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STAFF PAPER
ORO-SP-160

Programing Computer-Assisted Transportation Planning

XEROX

by

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PROBLEM

To provide a reference document for the use of computer installations, computer programers, and systems-analysis groups expected to be working primarily with the computer aspects of the new planning procedure.

FACTS

This paper was specifically requested by the Army. In addition to the stated problem it provides detailed documentation for ORO-T-393,[1] which reports a computer-assisted strategic planning procedure developed by ORO for the US Army Transportation Corps (TC), with concurrence of Deputy Chief of Staff, Logistics (DCSLOG), and is designed to be used with it. [The procedure described in ORO-T-393[1] involves two main classes of steps (as shown in Fig. 1)—those executed as a judgment or decision process by experienced military or civilian personnel of TC and those executed by a digital computer.] It is also believed to have general interest, as a case history, to those engaged in developing computer-assisted logistics planning and gaming methods.

Each Department of the Army strategic logistics study (DA-SL) normally includes a campaign plan (CP), a logistic support plan (LSP), and an annex to the LSP from each of the seven technical services.* The principal function of the DA-SLs in the Army planning and programing cycle is to determine and justify midrange requirements for combat support troops and Class IV equipment. The detail of such requirements is spelled out in the technical services' annexes that thus constitute a major source for the troop and the materiel programs.

It has been established that the planning required to develop the technical services' annexes, using manual procedures for analysis and computation, takes 6 weeks. Moreover even this time does not permit repeated changes in assumptions or consideration of alternative courses of action.

*Occasionally one or more of these is omitted as not being required for the particular study.

SUMMARY

DISCUSSION

In line with its purpose, this paper breaks down naturally into five sections, corresponding to the five boxes on the right of Fig. 1. In each of these sections, generally the five following areas are treated:

(a) Function of the set of the computer programs used at this step in the planning system.

(b) Input data required at this step, with discussion of the forms on which these data will be furnished by the TC planner.

(c) Computations or analytic procedures required at this step, including detailed specifications of formulas and algorithms to be embodied in the computer programs.

(d) Specifications for the output required by the TC planner and/or by computer programs used later.

(e) Programing notes related to input treatment, the sequencing of computations, and special programing problems presented by this step.

Also given are a number of general block diagrams that summarize certain sections graphically and may assist in the program design for these sections.

Basis of Information

The basis for the information provided is fourfold.

First, the entire discussion is based on and integrated with the procedural analysis of TC strategic planning made by the research team in the course of the study. The user of this paper can check this area further by means of one of the documents listed below. However, in some cases he will have neither time nor inclination to do this, and this paper was designed specifically to be helpful in such cases. In sum many of the specific details recommended here for programs or for input or output treatment are based on a thorough analysis of TC operating practices, preferences, and peculiar requirements: the programer or system analyst using this paper may either take these on faith, check them through the references cited below, or make his own investigations at the Office of the Chief of Transportation (OCOFT).

Second, the information provided is based on ORO's experience in designing, coding, and test operating the prototype computer programs written for the Remington Rand 1103 A computer. These programs are not reproduced here (although they can be made available on request) for two reasons: they reflect the particular configuration of the 1103 A and hence are of limited general use, and, more important, as experimental prototypes they include many features now obsolete. They were, of course, used as part of the basis for the five generalized block diagrams appearing here.

Third, the operational tests of the prototype programs are a part of the basis for statements made here. Three tests were made over the period October 1959–October 1960,[1] each involving the production of some part of a Transportation Annex (t-annex) to a particular DA-SL by computer.

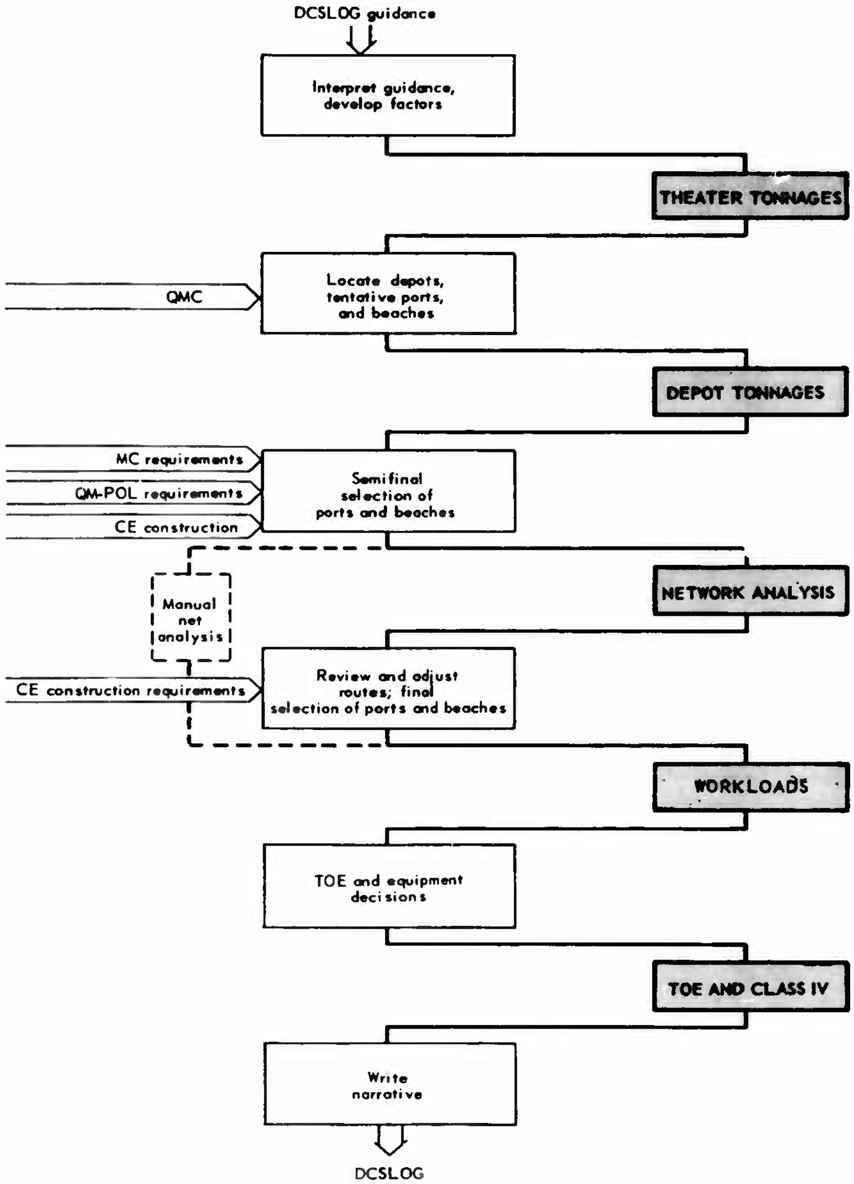

Fig. 1—Planning Process

Fourth, the design of the computer-assisted planning procedure as a whole has been called on and kept in mind constantly during the writing of the present document.

Reference Documents. ORO-T-393 is the best reference for over-all design of the planning system.

ORO-TP-15[2] provides purely mathematical information on transportation network analysis; discussions of the same subject with different orientation are to be found in this paper (section "Utilization of Rail and Highway Networks," subsection "Computations"), and in ORO-T-393[1], App B.

Purposes of This Paper

This paper was prepared to serve four closely related purposes.

First, it is intended to provide detailed documentation for the statements in ORO-T-393,[1] which, as ORO's general report to the Army on the study, draws conclusions and makes recommendations about the proposed computer-assisted planning system. This purpose could have been served by an appendix to ORO-T-393[1] of course, but the Army specifically requested a separate publication to fulfill a second purpose.

Second, a guidance paper is needed for the use of systems analysts and programers now or in future engaged in adapting and reprograming these procedures for other computers. Specifically, by agreement between TC and The Adjutant General's Office (TAGO), the plan at date of writing calls for reprograming for the IBM Model 705 computer.

Third, a program maintenance guide and reference book will be helpful for some time in the future and will facilitate liaison between TAGO and TC.

Fourth is a purpose related to TC's stated intentions of exploiting these methods wherever substantial payoff is in prospect. The procedures described here apply to midrange planning, but the possibility of applying them to contingency plans and to operational planning exists. This would require designing new but similar sets of programs, and this paper should provide a useful point of departure for those undertaking the task.

PROGRAMING COMPUTER-ASSISTED TRANSPORTATION PLANNING

INTRODUCTION

This paper describes the computer aspects of the computer-assisted planning procedure developed by ORO for the US Army TC. The complete report of the new planning procedure and its development was published as ORO-T-393.[1] Of course the present paper documents and may be used in conjunction with ORO-T-393.[1] Its separate publication (at Army request) is intended to better serve the purposes of computer installations and systems-analysis groups that are now or will later be implementing the computer-assisted planning procedure.* However, this paper is self-contained and may be read without reference to ORO-T-393.[1]

Background

The planning procedure considered in this paper is part of the US Army midrange planning and programing system (see FM 101-51[3] especially Chap. 3). Under each Army Strategic Objectives Plan (ASOP) a series of campaign plans are prepared by Deputy Chief of Staff for Operations (DCSOPS). Each of these constitutes the first step in the preparation of a DA-SL, which in turn determines an important segment of the Army's midrange requirements.

Each DA-SL includes a plan by DCSLOG for logistic support of the campaign and an annex to the LSP by each of the seven technical services. It is these annexes that determine the detailed requirements for support, and each of them normally includes a listing of Class IV equipment requirements by item and of the required combat support troops by TOE unit; the former constitutes an input to the materiel program via the materiel planning studies of the technical services; the latter constitutes an input to the troop program and hence indirectly contributes to determination of Class II requirements for the materiel program (for further details see "Strategic Logistics Studies (DA-SL's)"[4] and appropriate sections of ORO-T-393.[1]

Producing the Transportation Annex

The t-annex to the DA-SLs represents, then, the plan for transportation support of a particular campaign under the ASOP, with itemized listings of

*Specifically at time of writing the Systems Engineering Section, Data-Processing Branch, TAGO, is engaged in implementing the procedure for TC; the Automatic-Data-Processing Programing Section is expected to be so engaged in the near future. Also this paper is planned for later use by similar groups, either Army or contractor, implementing the study extension that is going forward under DCSLOG.

requirements and supporting data. Specifically the t-annex includes, in addition to the general narrative statement of the concept of support, with conclusions and recommendations, appendixes reporting tonnage requirements; rail, highway, and port and beach maps; troop-unit requirements; total personnel requirements; gross and net Class IV materiel requirements; and certain subsidiary requirements.

Before development of the computer-assisted procedure, the t-annex was produced by methods that, at least in main outlines, may be considered standard among the Army technical services. A central planning authority (currently in TC this is the Plans Division, OCOFT), coordinates the procedure. Details of the concept of support and actual determination of requirements are assigned to individuals who, by experiencing the actual conduct of military support operations or through long service in military planning in wartime, or both, are equipped to estimate requirements for the particular situation envisaged. The strength of this method is that it exploits the Army's accumulated wartime experience and seasoned military judgment. One drawback is its lack of flexibility. The numerical calculations and subsidiary analyses* involved tend to become burdensome to the planners, and in any event the procedure inhibits repeated trials and deliberate variations to test the effects of assumptions.

Objective of the Research Study

ORO's study for TC had as its objective the reduction to computer-assisted form of the procedure for producing the t-annex. The purpose was to increase the efficiency of the planning procedure by gaining the capability to test several different assumptions and to consider alternative courses of action without increasing the total elapsed time to completion of the plan. An important further requirement is that the military soundness and validity of the results of the procedure be maintained or improved in the computer-assisted form. This is a decisive consideration in the design of the computer programs and of detailed procedures for transmitting planning decisions to the computer installation. In other words the prime consideration here is not efficient utilization of the computer as such but the creation of an optimum working situation for the skilled and experienced military planner (of course, the two can be concomitants, which is desirable).

Results of the Study

A principal finding of the ORO study was that the elements of the transportation planning procedure can be separated into two main classes. Figure 1, which is a schematic outline of the computer-assisted procedure itself, illustrates this separation. The boxes on the left of Fig. 1 show essentially steps of judgment involving experience, intuition, and numerous formal and informal interactions with other expert individuals in the Army establishment. These interactions are indicated in Fig. 1 by arrows summarizing conferences between TC and, e.g., the Corps of Engineers (CE) or the Quartermaster Corps (QMC). Shown on the right of Fig. 1 are steps that at least in principle are

*An example of the latter in TC is analysis of large transportation networks to determine utilization.

susceptible of being programed for a modern digital computer. The first and second steps, e.g., gross theater tonnage calculations and the computed apportionment of such tonnage to the subdivisions of major support missions throughout the theater, are straightforward programing tasks depending simply on an accurate knowledge of the kinds of calculations and the ranges of parameters likely to be considered by the Army and the TC in the present time frame. The third step, computer analysis of transportation networks, is not entirely straightforward and depends on the design and verification of an appropriate set of algorithms. The fourth step is a straightforward summarization of previously derived quantities, resulting in three tabulations that appear in the final t-annex. The fifth step involves the translation of tonnage workloads and other work units into an itemization of specific Class IV equipment and TC TOE units required to sustain these workloads and work units.

Because the computations are partitioned into the five areas just mentioned, separated by necessary actions and decisions of the TC planner, the problem of transmitting information between the planner and the computer installation differs from that encountered in representative data-processing applications. The total input required for all five programs falls into a fairly large number of distinct categories. These cannot all be transmitted at one time, since the input for each program depends in part on results of preceding programs as well as on other information that becomes available to the planner at varying times during the process. The same program may also be required several times during the procedure as a result of changes to one or more of the assumptions employed in the initial run.

Status of Study

To date of writing the computer-assisted procedure for producing the t-annex has received three operational tests of increasing scope. By September 1960, the time of the last of these tests, TC had in effect gone over to the computer-assisted procedure and relied on it in preparing the particular t-annex involved. In that trial the prototype computer programs written by ORO during the research were used, as was ORO's scientific-type computer installation (the 1103 A). The input-data forms presented in this paper are those developed at that time and currently in use by TC.

At TC's request TAGO has agreed to write operational programs for their computer installation (the 705), based on the prototypes and suited to the procedure described in this paper, and to commence support of TC for production of the t-annex as soon as these programs are complete.

At the same time, at the request of DCSLOG and in cooperation with the technical services, ORO is undertaking a study with the objective of extending computer-assisted procedures to all seven technical service annexes to DA-SLs.

Plan of Paper

In accordance with its purpose the text of this paper includes five sections centering respectively around the five boxed steps on the right of Fig. 1. In each section the five following matters are treated:

(a) Function of the set of computer programs used at this step in the planning system.

(b) Input data required at this step, with discussion of the forms on which these data will be furnished by the TC planner.

(c) Computations or analytic procedures required at this step, including detailed specifications of formulas and algorithms to be embodied in the computer programs.

(d) Specifications for the output required by the TC planner and/or by computer programs used later.

(e) Programing notes related to input treatment, the sequencing of computations, and special programing problems presented by this step.

GENERAL TERMINOLOGY

Before describing each of the five computer programs in detail, a number of basic terms are introduced in this section that occur frequently and have standard meanings throughout this paper. The discussion is limited to ıor-mation relevant in designing the computer programs. The military significance of the concepts represented by these terms is discussed in a related publication directed more specifically to the TC planner.[1]

Tonnage Categories

The total tonnage of interest to the TC falls into two categories: bulk petroleum, oil, and lubricants (POL) and dry cargo, which by definition includes all other materiel handled by TC, including packaged POL. Dry cargo is further subdivided into initial equipment, accompanying supplies, resupply (or replenishment supplies), and buildup tonnage. These four types of dry-cargo tonnage are individually computed from logistic planning factors and are later combined to obtain certain composite expressions important to the TC, in a manner described later.

Time Intervals

For computational purposes the total period of time spanned by a campaign is considered to be partitioned into a number of intervals of equal length, termed "basic time periods." The average daily tonnage during each basic time period is computed and used as the basis for estimating TC requirements. Thus tonnage fluctuations within a basic time period are disregarded in this planning context. The formulas given in this paper for computing tonnages are based on the assumption that a 30-day month has been selected as the length of a basic time period. However, by appropriate scaling of the input logistic factors it is possible to alter the length of a basic time period without changing the structure of these formulas.

The first two computer programs compute certain tonnages for each basic time period. The last three are applied only to certain "selected" time periods of particular concern to the TC. Normally the TC planner will designate as selected time periods those months that involve maximum TC effort in their respective calendar quarters.

Consumer Categories

The TC handles tonnage destined for a variety of distinct consumer groups. In addition to the US Army, these may include the US Air Force, allied military forces, civilian labor (static and mobile), prisoners of war, and others. Each consumer group having its own distinctive consumption rate and other planning factors is termed a "user" in the remainder of this paper. The kinds and number of users will obviously vary from one campaign to the next.

Geographical Terms

In the first computer program, in which tonnages are computed for each user and basic time period, the theater is considered as being partitioned into a small number of general regions termed "sections." These are chosen in such a way that the logistic factors associated with a particular user may vary from section to section.

In the second program sectional tonnages are apportioned to more specific theater locations called "destinations." These are best thought of as smaller subsections within each section rather than geographical points, since a portion of the total tonnage (initial equipment and accompanying supplies) is transported directly to the using units rather than to specific depots and supply points. The precise locations of these using units are not indicated in all cases in the campaign plan.

In order to determine definite routings of tonnage in the third computer program, specific ports, beaches, pipeheads, and locations of prestockpiles must be identified. These are referred to collectively as "origins."

COMPUTATION OF DRY-CARGO TONNAGES

Program Function

This program, the first one listed on the right-hand side of Fig. 1, translates basic information regarding the population phasing and planning factors for each user into estimates of the dry-cargo tonnage involved in the campaign. Tonnages are computed for each user, basic time period, and theater section. Two printed reports or "printouts" are produced showing the tonnage for each of the four categories of dry cargo, as well as for several composite expressions derived from these categories. A magnetic-tape file is also produced, which forms part of the input to the second computer program.

Program Input

In order to relate input and derived quantities to a specific user, time period, and theater location, a system of subscripts is employed. Table 1 gives the subscripts identified with the four parameters of time, user category, theater section, and destination. It also shows for each parameter the maximum value that the programs should be designed to accommodate in order to meet anticipated requirements of TC planners. Use of the subscript d, related to theater destinations, is discussed in the next section.

TABLE 1

BASIC PARAMETER SUBSCRIPTS AND RANGES

Parameter	Subscript	Range of values
Time period	t	1–36
User	u	1–15
Theater section	s	1–4
Destination	d	1–20

As an example of the use of this system of subscripts, the daily rate of resupply during basic time period t for user u in theater section s is denoted by $R_{t,u,s}$. The total daily resupply for user u during period t can then be written as

$$\sum_s R_{t,u,s}$$

i.e., resupply by section summed over all sections. Unless otherwise noted summations are to be taken over the entire meaningful range of the specified index.

Table 2 lists the input data that must be given and the standard symbol used to represent each input category. This information is furnished by the TC planner on two forms. Form 14, Fig. 2, gives the total and incremental population data $P_{t,u,s}$ and $p_{t,u,s}$. Each sheet contains all such data for one user. The campaign plan frequently expresses population phasing data in time intervals that are multiples of a month, the basic time period. For example, it may specify that the population of user u in section s at day 90 (the start of period 4) is 100,000, and that at day 180 (the end of period 6) it is 160,000. In this case one line of Form 14 will give all population data for periods 4, 5, and 6. The numbers 4 and 6 will be entered in the second and third columns respectively, and 100,000 and 60,000 will be entered under columns subheaded "ACC" and "Δ" corresponding to the appropriate theater section. Similar figures for the other sections will also be entered on the same line. The first column of this form is not essential for computational purposes. It is used to relate time periods to the frame of reference of M-day or D-day. Returning to the numerical example above, the program will interpolate linearly to obtain

$$P_{4,u,s} = 100{,}000 \qquad p_{4,u,s} = 20{,}000$$

$$P_{5,u,s} = 120{,}000 \qquad p_{5,u,s} = 20{,}000$$

$$P_{6,u,s} = 140{,}000 \qquad p_{6,u,s} = 20{,}000$$

If there are fewer than four sections, appropriate columns of Form 14 are left blank.

Form 14A, Fig. 3, contains the other input data indicated in Table 2. One sheet of this form applies to each user. The column headed "Effective Period" indicates the basic time period in which the factors on the corresponding line become effective, superseding those on any preceding lines. The first line always applies to period 1. Additional lines are used if and only if at least one of the factors changes at a later time.

The logistic factors for a given user are frequently the same for all theater sections. If this is the case, a 0 is entered in the second column and the factors are assumed to be applicable to all sections. Otherwise a line will be given for each section with the appropriate section code number and factors.

Computations

Basic Tonnages. For a given period, user, and section, the daily tonnage of each of the four categories of dry cargo is denoted as follows: $I_{t,u,s}$, initial equipment; $A_{t,u,s}$, accompanying supplies; $R_{t,u,s}$, resupply; and $B_{t,u,s}$, buildup.

The first three of these are computed by means of the following formulas:

$$I_{t,u,s} = \frac{(F^1_{t,u,s})\,(p_{t,u,s})}{30} \quad \text{short tons/day}$$

$$A_{t,u,s} = \frac{(F^2_{t,u,s})\,(p_{t,u,s})}{30} \quad \text{short tons/day}$$

$$R_{t,u,s} = \frac{(F^3_{t,u,s})\,(P_{t,u,s})}{30} \quad \text{short tons/day}$$

The computation of buildup tonnages is somewhat more complicated. Let t,u,s be an arbitrary but fixed time-user-section combination. For each of the $p_{t,u,s}$ men arriving in section s during period t, $(F^4_{t,u,s})\,(F^6_{t,u,s})/30$ tons of buildup must be provided in section 1. Moreover this quantity is to be built up uniformly over $F^5_{t,u,s}$ days, or $F^5_{t,u,s}/30$ basic time periods. Thus this population increment

TABLE 2

PROGRAM I INPUT CATEGORIES, SYMBOLS, AND DIMENSIONS

Symbol	Input category	Dimensions
$F^1_{t,u,s}$	Initial equipment factor	Short tons/man
$F^2_{t,u,s}$	Accompanying supply factor[a]	Short tons/man
$F^3_{t,u,s}$	Resupply factor	Short tons/man/month
$F^4_{t,u,s}$	Buildup factor	Short tons/man/month
$F^5_{t,u,s}$	Buildup duration (no. of days, from time of arrival, within which buildup for a given population increment must be completed)[b]	Days
$F^6_{t,u,s}$	Buildup level in section 1 (no. of days of supply to be provided in section 1 for each man arriving in section s)	Days
$F^7_{t,u,s}$	Buildup level in section 2	Days
$F^8_{t,u,s}$	Buildup level in section 3	Days
$F^9_{t,u,s}$	Buildup level in section 4	Days
$P_{t,u,s}$	Total population of user u in section s, at the start of period t	Men
$p_{t,u,s}$	Population increment for user u in section s during period t[c]	Men
$K^1_{t,u,s}$	The fraction of resupply to be transported to the theater by intertheater airlift	None
$K^2_{t,u,s}$	The fraction of resupply to be transported forward to section s by intratheater airlift[d]	None
$K^3_{t,u,s}$	The fraction of initial equipment to be cleared from the ports by the TC	None

[a]This factor normally represents 30 days of supplies accompanying the incoming personnel.

[b]This factor must be a multiple of 30.

[c]This increment should not include intratheater movements between sections since it is used as the basis for computing initial, accompanying, and buildup tonnages.

[d]This factor is not applicable when $s = 1$, for reasons given in the following discussion.

USER CODE ________

SL INPUT DATA FOR ADPS - POPULATIONS										
BASIC PERIOD BEGINNING	PERIOD NUMBER		SECTION 1		SECTION 2		SECTION 3		SECTION 4	
	BEG	END	ACC	Δ	ACC	Δ	ACC	Δ	ACC	Δ

TCPLN FORM 12 AUG 68 14

Fig. 2—Input Form for Population Data

USER CODE ____________

SL INPUT DATA FOR ADPS - FACTORS

EFFECTIVE PERIOD	SECTION	I ST/MAN	A ST/MAN	R ST/MAN/MO	B ST/MAN/MO	B LEVEL DAYS				PERIOD DAYS	INTER-AIR % OF R	INTRA-AIR % OF R	% OF I TC HANDLED
						S 1	S 2	S 3	S 4				

TCPLN FORM 12 AUG 60 14 A

Fig. 3—Input Form for Logistic Factors

requires a daily buildup tonnage, to be stored in section 1 of

$$\frac{(F^4_{t,u,s})\,(F^6_{t,u,s})}{30\,F^5_{t,u,s}} \quad \text{short tons/day}$$

during each day of periods t, $t+1$, . . . , $t+(F^5_{t,u,s}/30) - 1$. This same troop increment requires daily buildup tonnages in sections 2, 3, and 4. These are obtained by substituting F^7, F^8, and F^9 respectively for F^6 in the above formula. (These tonnages are also spread uniformly over $F^5_{t,u,s}/30$ periods.) By applying these formulas to each troop increment and superimposing all buildup tonnages destined for the same section in the same period, $B_{t,u,s}$ is obtained for each t,u,s combination.

Composite Tonnages. Certain expressions derived from I, A, R, B, K^1, K^2, and K^3 are of special interest to the TC. In reading the following explanation, Fig. 4 should be consulted for a schematic representation of these tonnages and their interrelations. For simplicity the subscripts t,u,s are omitted in the following expressions, although a single arbitrary period-user-section combination is being considered.

The total daily dry-cargo tonnage entering the theater (for this period, user, and section) is simply

$$I + A + R + B$$

This is divided into two categories. The total intertheater airlift is

$$K^1 R$$

and the remainder constitutes the total "port workload"

$$I + A + (1 - K^1)\, R + B$$

Of the total port workload, the TC is responsible for the clearance of all tonnage except the fraction $(1 - K^3)$ of the initial equipment, which is moved organically. Thus the total "port clearance" of interest to the TC is

$$K^3\, I + A + (1 - K^1)\, R + B$$

Port clearance in turn falls into two categories. The amount of intratheater airlift generally exceeds the amount of intertheater airlift. For this reason a portion of the resupply entering ports and beaches must be moved to airfields to be airlifted forward. This amount of resupply is

$$(K^2 - K^1)\, R$$

The remainder of port clearance proceeds by surface transportation means to the appropriate destinations. This tonnage is termed the dry-cargo "lines of communication (LOC) workload" and is equal to

$$K^3\, I + A + (1 - K^2)\, R + B$$

It is important to note that the term LOC workload, as used here, will always refer to the surface LOC, excluding the air LOC.

One exceptional case must be noted. If the theater section under consideration is section 1, which is normally taken to coincide with the base section (BASEC) or a part of BASEC, intratheater airlift of resupply is not applicable. In this case there is no surface movement of resupply from ports to airfields,

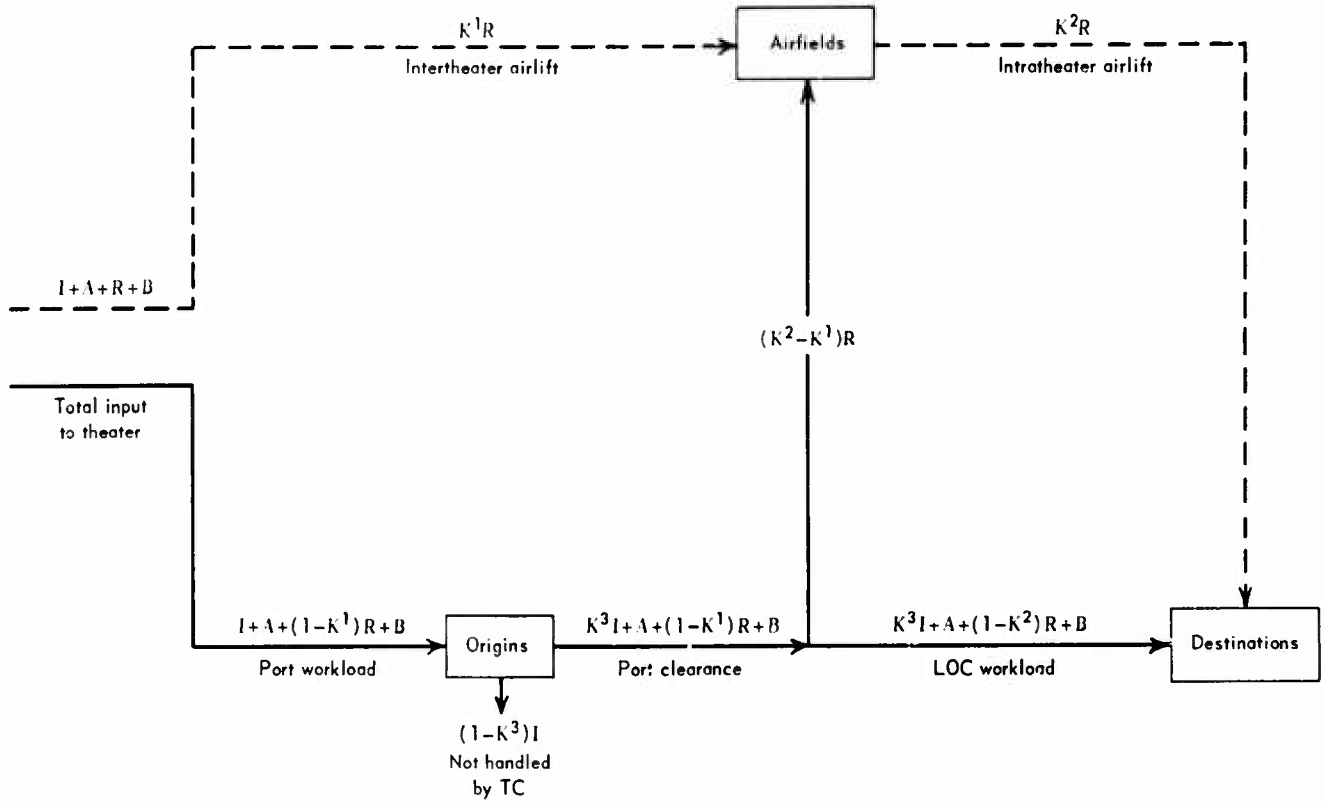

Fig. 4—Schematic Explanation of Composite Expressions
Derived from I, A, R, and B

——— Surface movements
– – – Airlift

and the LOC workload is the same as port clearance. Computationally this ceases to be a special case if K^2 is taken equal to K^1 for $s=1$.

Program Output

Two printed reports, or printouts, and one magnetic-tape file are produced by this program. Figure 5a shows a format for one time period of the

THEATER TONNAGE BY USER CATEGORY FOR PERIOD XX (ST/DAY)

User code	Port workload	Intertheater airlift	Resupply	Initial equipment	Accompanying supplies	Buildup	Port clearance
1							
2							
3							
4							
5							
6							
Total							

A. TONNAGES ITEMIZED BY USER

SUMMARY OF THEATER TONNAGES (ST/DAY)

Period	Port workload	Intertheater airlift	Resupply	Initial equipment	Accompanying supplies	Buildup	Port clearance
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

B. SUMMARY OF TONNAGES

Fig. 5—Output Formats for Theater Tonnages

first printout, entitled "Theater Tonnages by User." For each period this report has one line per user, as shown. The derivation of the quantities in the seven data columns of this printout is given in Table 3. Note that a total is also printed at the bottom of each column.

The second printout, the format of which is shown in Fig. 5b, consolidates on a single sheet the totals from the preceding printout. From this report critical periods, i.e., periods having peak loads, can be readily identified. The user composition of these critical tonnages is then determined by the planner from the appropriate sheets of the first printout. The formats depicted in Fig. 5 need not be adhered to exactly if an equally readable arrangement of the same data, acceptable to TC, proves more practical to produce.

TABLE 3

DERIVATION OF DATA FOR PRINTOUT OF TONNAGES

Column heading	Derivation
Port workload	$\sum_s [I_{t,u,s} + A_{t,u,s} + (1-K^1_{t,u,s}) R_{t,u,s} + B_{t,u,s}]$
Intertheater airlift	$\sum_s \left(K^1_{t,u,s} R_{t,u,s}\right)$
Resupply	$\sum_s R_{t,u,s}$
Initial equipment	$\sum_s I_{t,u,s}$
Accompanying supplies	$\sum_s A_{t,u,s}$
Buildup	$\sum_s B_{t,u,s}$
Port clearance	$\sum_s [K^3_{t,u,s} I_{t,u,s} + A_{t,u,s} + (1-K^1_{t,u,s}) R_{t,u,s} + B_{t,u,s}]$

In addition to producing these printouts, a magnetic-tape file containing the dry-cargo LOC workload for each t,u,s combination is generated. For any given t,u,s this quantity is denoted by $W_{t,u,s}$ and is computed from the relation

$$W_{t,u,s} = K^3_{t,u,s} I_{t,u,s} + A_{t,u,s} + (1-K^2_{t,u,s}) R_{t,u,s} + B_{t,u,s}$$

Programing Notes

This subsection contains various notes intended to assist in the detailed design of the computer program. They stem from experience by the research team in the design and use of a prototype of this program written for a Remington Rand 1103 A computer.

Arrangement of Input Data. For each t,u,s combination the following must be given: $F^1, F^2, \ldots, F^9, K^1, K^2, K^3$, P, and p. It is natural to separate the population data from the logistic factors, thus having two input decks of punched cards. The format of the population deck can be essentially the same as that of input Form 14, Fig. 2, submitted by the TC planner. In this case each card contains these fields:

$$u,\ t',\ t'',\ \overline{P}_1,\ \overline{p}_1,\ \ldots,\ \overline{P}_n,\ \overline{p}_n$$

where t' and t'' are the first and last basic time periods spanned by a given line of Form 14, $\overline{P}_s$ and $\overline{p}_s$ denote the total and incremental population figures in section s during this interval, and n is the number of theater sections (not exceeding four). This deck should be in user sequence and time sequence within each user group. For any given user $t' = 1$ on the first card and $t'' = T$ on the last card, where T is the total number of basic periods spanned by the campaign. If a card spans only one basic period, $t' = t''$ and $\overline{P}$ and $\overline{p}$ are already in standard form. In other cases P and p for basic periods must be derived from $\overline{P}$ and $\overline{p}$ by linear interpolation, spreading the population increment $\overline{p}$ uniformly over the $t'' - t' + 1$ basic periods spanned by the card.

The format of logistic factor input cards can follow that of Form 14A, Fig. 3, very closely. If the card fields are arranged in the same order as on this form, each card will have the following format:

$$u,\ t,\ s,\ F^1,\ F^2,\ F^3,\ F^4,\ F^6,\ F^7,\ F^8,\ F^9,\ F^5,\ K^1,\ K^2,\ K^3$$

Not all values of t need be represented on cards. There must be a card, or set of cards, for each user for $t=1$. There may also be change cards, for which the field t indicates the start of the period at which previously given factors are to be superseded. The field s may contain 0 or a valid section number. In the former case the factors should be used for all sections. In the latter case they apply only to the indicated section, and a card must be provided for every section with the same u and t codes. This deck should be in user sequence and time sequence within each user group.

In addition to the population data and logistic factors, the total numbers of periods, users, and sections must be known. In the prototype program these were introduced by means of a third type of punched card. It may prove more convenient to insert these three numbers manually in the final version.

Computational Sequence. If it were not for buildup tonnages, the computations for any t,u,s combination would be independent of those for any other, and the set of all such combinations could be processed in any convenient order. However, since the buildup tonnage for a population affects all sections and an indefinite number of periods (determined by $F^5_{t,u,s}$), it is convenient to arrange the computations in user sequence. Since there are at most 36 periods, 4 sections, and 8 quantities per t,u,s combination, corresponding to the seven data columns of Fig. 5 and $W_{t,u,s}$, the number of computed quantities for a fixed user will not exceed 1152. Thus all results for a user can be contained easily in core.

Figure 6 is a flow chart describing a feasible general sequence of computations for this program, assuming that tonnages are initially computed in user sequence and then sorted into time sequence prior to the output editing subroutines.

Output Format. Since the report shown in Fig. 5a contains relatively few lines for each period, it is suggested that two or three periods be recorded on each sheet. Three is quite desirable since then each sheet summarizes a calendar quarter. However, this may not be feasible in the case of the maximum number of users (15).

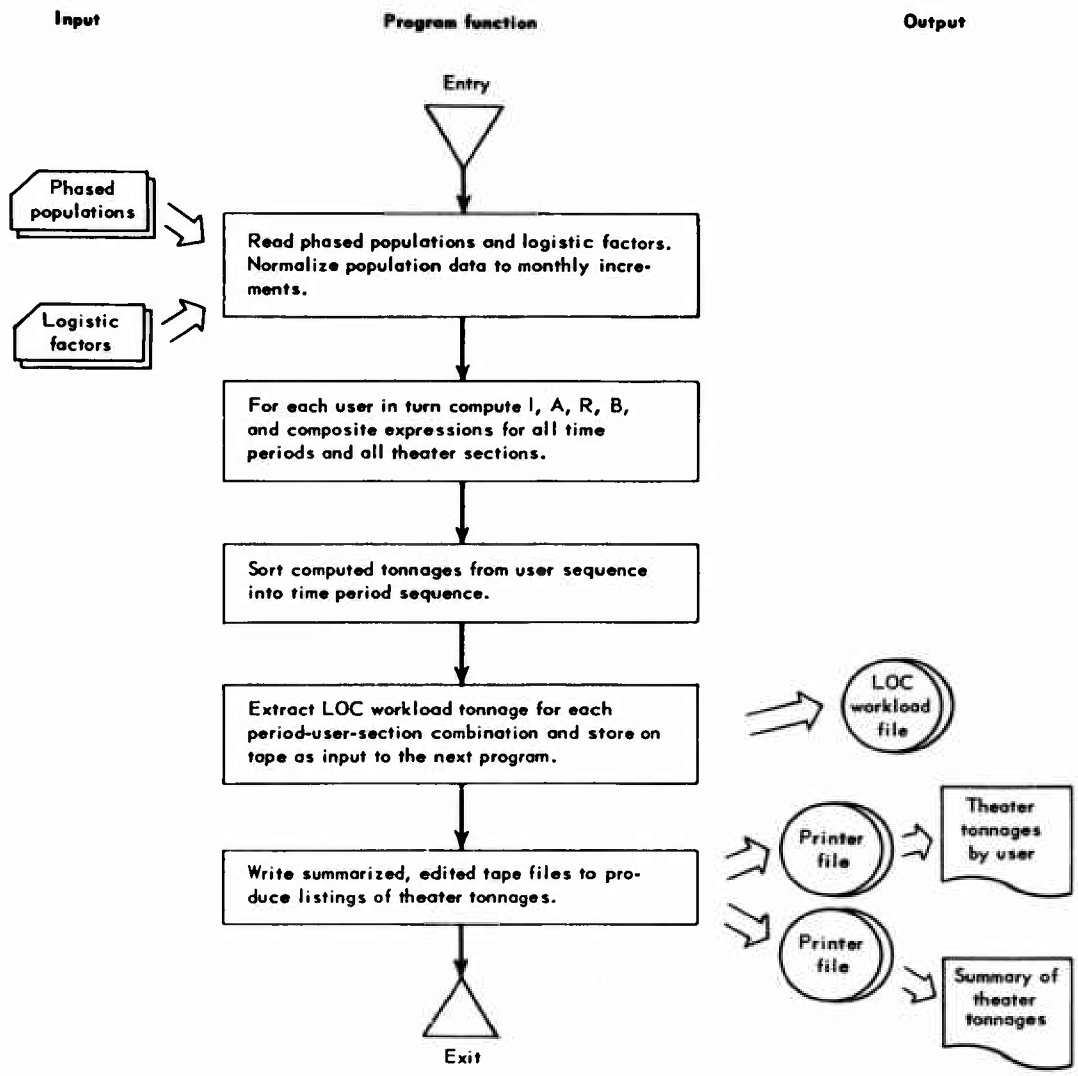

Fig. 6—General Flow Chart for Tonnage Computations

APPORTIONMENT OF LOC DRY-CARGO WORKLOADS TO DESTINATIONS

Program Function

In this program the sectional tonnages previously computed are apportioned to more specific destinations within each section. The apportionment is based on information concerning the number of destinations in each section and their relative utilization. As in the case of the first program the calculations are performed for each basic time period of the campaign, and the output consists of a report presenting destination tonnages phased in time and itemized by user category.

TABLE 4

PROGRAM 2 INPUT CATEGORIES AND SYMBOLS

Symbol	Input
$L_{t,d}$	Theater section in which destination d is located during period t
$Q_{t,u,d}$	Percentage of the sectional LOC workload tonnage for user u in period t that is to be apportioned to destination d[a]

[a]For fixed t and u the equation $\sum_d Q_{t,u,d} = 100$ must be satisfied.

Program Input

The values of $W_{t,u,s}$ produced by the preceding program for each meaningful combination of t,u,s from a part of the input to this program. The remaining input categories are shown in Table 4.

Changes in sectional boundaries are reflected by letting $L_{t,d}$ vary with t. Thus if destination d is in section 3 until the start of period t' and is in section 2 thereafter, the input will specify that $L_{t,d} = 3$ for $1 \leq t < t'$ and $L_{t,d} = 2$ for $t \geq t'$. Similarly destinations are phased in or out by appropriate phrasing of the input Q. If destination d is to handle 30 percent of user u's tonnage (in section $L_{t,d}$) until period t', and none thereafter, the input will specify that $Q_{t,u,d} = 30$ for $1 \leq t < t'$ and $Q_{t,u,d} = 0$ for $t \geq t'$.

SECTION LOCATIONS OF SUPPLY POINTS																					
	Effective Period	SUPPLY POINTS																			
SECTIONS																					

TCPLN FORM 14C 29 AUG 60

Fig. 7—Input Form for Destination Locations

Effective Period	User	Percent User Demand, By Section, To Supply Point																			
		Supply Points																			

TCPLN FORM 29 AUG 60 14 B

Fig. 8—Input Form for Destination Usage Factors

The $L_{t,d}$ information is provided by the TC planner on Form 14C, shown in Fig. 7. Each column except the first corresponds to one destination, termed a "supply point" on this form. Each row corresponds to one period, whose number is given in the first column. Data are given by exception, i.e., data for $t = 1$ are always given, and additional lines are given when and only when one or more of the $L_{t,d}$'s change in time.

The $Q_{t,u,d}$'s are given on Form 14B, Fig. 8. Here there must be a line for each user, for $t = 1$, and additional lines to record changes, if any.

Destination	User code	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	1						
	2						
	3						
Total							
2	1						
	2						
	3						
Total							

Fig. 9—Output Format for Destination Tonnages

This is a multipage report grouping six periods per page. The report format is variable, its length being determined by the number of destinations and users.

Computations

Let $W_{t,u,d}$ represent the daily dry-cargo LOC workload to be assigned to depot d for given t and u. If s is taken as the section in which d is located at this time, viz., $s = L_{t,d}$, then $W_{t,u,d}$ is simply computed by using the relation

$$W_{t,u,d} = Q_{t,u,d} W_{t,u,s}$$

Program Output

A single printout is produced by this program that simply itemizes $W_{t,u,d}$ for each meaningful t,u,d combination and gives also $\sum_u W_{t,u,d}$ for fixed t and d.

Figure 9 illustrates a format for this report, patterned after the one produced by the corresponding 1103 A prototype program. Each sheet covers six basic time periods. The number of lines is dependent on the total number of users and destinations. If these are large the data overflow to additional sheets.

Programing Notes

Arrangement of Input Data. The data given on Forms 14C and 14B, Figs. 7 and 8 respectively, can be conveniently grouped in two decks, each card corresponding to one line of one of these forms. In the corresponding prototype program each card of destination-location data has the following fields:

$$t,\ L_{t,1},\ L_{t,2},\ \ldots,\ L_{t,D}$$

where D is the total number of destinations and t is the time period in which the data become effective. Since each $L_{t,d}$ is a single digit denoting a theater section number, these data can be contained on a card even in the extreme

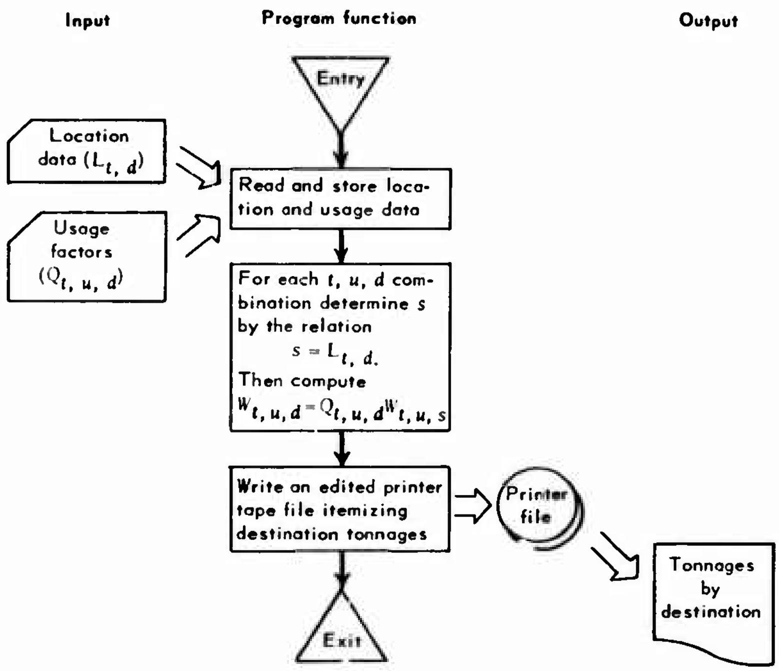

Fig. 10—General Flow Chart for Tonnage Apportionment

case when $D = 20$. Each card of relative usage data ($Q_{t,u,d}$'s) has the following fields:

$$t,\ u,\ Q_{t,u,1},\ Q_{t,u,2},\ \ldots,\ Q_{t,u,D}$$

Each $Q_{t,u,d}$ is a 3-digit number between 000 and 100. When $D = 20$ these data can be contained on one card, but only if no blank columns separate $Q_{t,u,s}$ and $Q_{t,u,s+1}$.

In the case of both decks the cards are sorted on t, and the program tests that data are present for $t = 1$.

The input tape file of sectional LOC workloads $W_{t,u,s}$ consists of one quantity per t,u,s combination. This file attains a maximum size of $36 \cdot 15 \cdot 4 = 2160$ computer words. If storage space does not permit containing the entire file at one time, it can be conveniently partitioned into one block per period or group of periods.

Computational Sequence. A general flow chart for this program is given in Fig. 10. If T, U, and S denote the total numbers of periods, users, and sections respectively, and the $W_{t,u,s}$'s are stored in TUS consecutive locations the first of which is location L, then $W_{t,u,s}$ will be in location $L + (t - 1)\,US + (u - 1)\,S + (s - 1)$. This formula forms the basis for an address-modification procedure for locating $W_{t,u,s}$, after s is obtained from the relation $s = L_{t,d}$.

UTILIZATION OF RAIL AND HIGHWAY NETWORKS

Program Function

This program determines specific rail and highway routings of required tonnages from origins to destinations, consistent with given network restrictions and upper limits on the tonnages that originate at each port and beach. If it is not feasible to meet all requirements using the available networks, as much as possible is routed and bottlenecks are identified. The determination of routes for either dry-cargo or bulk POL movements for one time period constitutes one program run. The number of runs depends on the number of critical periods designated by the planner for analysis and on whether or not dry-cargo and bulk POL routings require computer determination of routes. In certain theaters the planner may elect to determine network utilization manually.

Program Input

Basic Network Information. The primary network input consists of a master rail and highway file. Junction points and terminal points in the rail and highway networks are called "nodes" and are assigned code numbers. The portion of network between two adjacent nodes is termed a "link." The master file consists of an itemization of all primary links in the theater. For each link the following data are given: the code numbers of the nodes it connects, its length in miles, and its one-way capacity in short tons per day. This information is furnished by the planner on Form 14D, shown in Fig. 11. A magnetic-tape file is then prepared for each mode.

Network Changes. In order to adjust the basic network files to the conditions of a particular time period, a set of network changes is generally required. These changes fall into three categories: addition of new links, deletion of existing links, and modification of the characteristics of existing links. This information is transmitted on Form 14F, Fig. 12, together with the number of the period in which each change is applicable.

Destination Data. Three types of information must be given for each destination. Two of these are related to location. The first is simply a cross reference between the destination code numbers assigned by the planner and the numbers of the nodes in the network that correspond to these points. The second is a destination "category code." This is a device that assures efficient utilization of the rail network. It is based on the fact that rail movements are generally more efficient than highway movements for long hauls. Destinations that can be reached by rail and are quite distant from any usable origins are

HIGHWAY ☐ RAIL ☐

Nodes Connected		Length	Capacity	Nodes Connected		Length	Capacity	Nodes Connected		Length	Capacity
From	TO	(Miles)	(ST/Day)	From	To	(Miles)	(ST/Day)	From	To	(Miles)	(ST/Day)

TCPLN Form 14 D, 31 AUG 60

Fig. 11—Input Form for Basic Network Data

Highway ☐ Rail ☐

Effective Period	Change Type*	LINKS		Length (miles)	Capacity (ST/Day)
		From	To		

TCPLN FORM 14 F
7 SEP 60

*CODE
1 - Add link
2 - Remove link
3 - Change link data to

Fig. 12—Input Form for Network Changes

designated as category 1 destinations. Categories 2 and 3 are applied to destinations of intermediate and relatively short distances from origins, respectively. Category 4 is reserved for destinations not suited for supply by rail either because they are too close to origins for rail to be practical or because they cannot be reached by rail. The precise way in which the program uses the category data is made clear later. Both the category data and the cross reference between destination numbers and network node numbers are entered on Form 14E, shown in Fig. 13. This is a dual-purpose form. When used in connection with destination data, only the first four columns are applicable.

The third type of input information concerning destinations consists of the daily rate of tonnage that must be moved by rail and highway to each destination. This information is provided on Form 14K, Fig. 14. Only those columns are applicable that correspond to periods selected for network analysis. The entries in the column "Supply Point" are destination code numbers corresponding to those given on Form 14E, Fig. 13.

Origin Data. As in the case of destinations it is necessary to provide a cross reference between origin code numbers and the corresponding network node numbers. The maximum tonnage that can be allocated to each origin is also required. This information is recorded on Form 14E, Fig. 13. When used for this purpose only the first column and the last three columns of this form are applicable. The entry in the column headed "Port" is simply an origin code number assigned by the TC planner.

Conversion Factors. Since the origin capacities are expressed in terms of port workload tons and the network and depot information is expressed in terms of LOC workload tons, conversion factors are required to convert to comparable figures. Specifically the planner must specify the theater-wide ratio of LOC workload to port workload for each time period. This is entered on the form shown in Fig. 15. (The other type of conversion factor depicted on this form is not required until the subsequent computer program.) In the case of POL network-analysis runs, the conversion factor is 1.

Computations

The complete network analysis for one time period involves the repeated solution of a certain type of network subproblem in such a way that an equitable apportionment of movements to rail and highway is achieved. Before the overall procedure is described, this restricted subproblem is presented, together with a computational algorithm for its solution.

Statement of the Central Subproblem. Consider a rail or highway network, with certain points distinguished as origins and destinations of materiel. It is assumed that there are at most 997 nodes and that they are assigned distinct code numbers between 002 and 998. (Numbers 001 and 999 are reserved for special purposes.) If the additional assumption is made that at most one link joins a given pair of nodes, without ambiguity the link joining nodes i and j can be denoted by the symbol (i,j).

Each link is assumed to have two parameters associated with it, which are nonnegative integers. One of these is its length, in miles, denoted by $l(i,j)$. The other is its one-way capacity, in short tons per day, denoted by $c(i,j)$. Each origin i has associated with it a positive integer C_i representing the maximum

Effective Period	Supply Point	Node	Category*		Port	Node	Capacity (ST/Day)

*Category Codes:
1 - First Rail Priority Group
2 - Second Rail Priority Group
3 - Third Rail Priority Group
4 - Rail Not Applicable

TCPLN FORM 31 AUG 60 14 E

Fig. 13—Input Form for Origin and Destination Data

Supply Point	REPORTING PERIODS											
	1	2	3	4	5	6	7	8	9	10	11	12

TCPLN Form 14K, 7 Sep 60

Fig. 14—Input Form for Origin Tonnages

Effective Period	LOC Workload / Port Workload	Port Clearance Workload / Port Workload

TCPLN Form 14 J
7 Sep 60

Fig. 15—Input Form for Tonnage Conversion Factors

LOC workload, in short tons per day, that can originate at node i. Each destination j has associated with it a positive integer R_j representing the daily tonnage required at node j.

To avoid mentioning a link twice, first as (i,j) and then as (j,i), an enumerating set S is introduced. This is a set or ordered pairs, one for each link, such that each link is represented by either (i,j) or (j,i) but not both. A flow in a link is an integer together with an orientation. If $(i,j) \in S$, the flow associated with (i,j) is denoted by $f(i,j)$ and the convention is adopted that $f(i,j) > 0$ indicates a flow from i to j whereas $f(i,j) < 0$ indicates a flow from j to i. In either case $|f(i,j)|$ is the magnitude of flow.

If a node i is fixed and the expression

$$Y(i) = \sum_S f(i,j) - \sum_S f(j,i)$$

is considered, then $Y(i)$ represents the sum of link flows directed away from node i minus the sum of link flows directed toward node i. $Y(i)$ is termed the net output at node i. Similarly $-Y(i)$ is the net input at node i.

To avoid considering multiple origins and destinations, the network is augmented by adding certain hypothetical nodes and links. Specifically let 000 and 999 represent two additional nodes called the source and sink respectively. For each origin i, add to S a link $(000,i)$ with parameters $c(000,i) = C_i$ and $l(000,i) = 0$. Similarly for each destination j, add to S a link $(j, 999)$ with parameters $c(j, 999) = R_j$ and $l(j, 999) = 0$. These hypothetical links are termed origin links and destination links respectively.

Consider now the following problem in the enlarged network. Find a set of link flows such that

$$Y(000) \text{ is maximized} \tag{1}$$

and the following conditions are satisfied:

$$Y(i) = 0 \text{ for all nodes except 000 and 999} \tag{2}$$

$$|f(i,j)| < c(i,j) \text{ for every link } (i,j) \tag{3}$$

In addition, as a secondary objective, besides maximizing $Y(000)$ it is desirable for the solution to involve a total ton-mileage that is as small as possible. The total ton-mileage for any flow pattern is given by the following expression:

$$\text{Total ton-mileage} = \sum_S |f(i,j)| \cdot l(i,j) \tag{4}$$

This problem [disregarding (4) for the moment] is equivalent to the problem of moving maximum tonnage from the set of origins to the set of destinations, subject to the restrictions that the net output from an origin i must not exceed C_i, the net input to a destination j must be at most R_j, input must equal output at all other nodes, and no link capacity may be exceeded. Since there are in general numerous solutions satisfying (1), (2), and (3), a solution is sought for which (4) is small, since rail equipment and truck-company requirements are roughly proportional to the rail and highway ton-mileages involved.

Solution of the Central Subproblem. The problem characterized by (1), (2), and (3) is a special case of the general linear-programing problem. However, because of the large number of variables and restraints involved in complex networks, a computational algorithm designed for this special case is employed, rather than a general procedure such as the simplex method. The algorithm is patterned in principle after certain "labeling processes" devised for network flow problems that have appeared in the literature.[5,6]

Consider the links as being arranged in a specific sequence (i_1, j_1), (i_2, j_2), . . . (i_k, j_k). Form a table of link information organized as shown in Table 5.

TABLE 5

LINK INFORMATION

From	To	Length	Capacity	Flow
i_1	j_1	$l(i_1,j_1)$	$c(i_1,j_1)$	0
$\updownarrow$	$\updownarrow$	$\updownarrow$	$\updownarrow$	$\updownarrow$
i_k	j_k	$l(i_k,j_k)$	$c(i_k,j_k)$	0

The procedure will gradually replace the zero flows by appropriate nonzero flows, continuing the replacement until a point is reached such that the set of link flows in the table is a solution to (1), (2), and (3).

A second table, related to node information, must also be set up. Table 6 shows the format.

TABLE 6

NODE INFORMATION

Node	Label	Approach link
000	0	—
001	∞	—
$\updownarrow$	$\updownarrow$	$\updownarrow$
999	∞	—

Thus at the outset a "label" $V(i)$ is assigned to each node i in the following manner: $V(000) = 0$, and $V(i) = \infty$ for all other nodes. (For computer purposes ∞ is represented by a large number, say 99999.) The "approach link" associated with a node has no significance at the start of the procedure. Now execute the following procedure.

(a) For each link i_n, j_n in turn, make the following replacements: If $V(i_n) + l(i_n, j_n) < V(j_n)$, and $f(i_n, j_n) < c(i_n, j_n)$, replace $V(j_n)$ by $V(i_n) + l(i_n, j_n)$ and list i_n, j_n as the approach link associated with node j_n. If $V(j_n) + l(i_n, j_n) < V(i_n)$, and $c(i_n, j_n) \neq 0$, replace $V(i_n)$ by $V(j_n) + l(i_n, j_n)$ and list i_n, j_n as the approach link associated with node i_n. If neither of the sets of conditions holds, make no replacements.

(b) If a replacement is made for at least one link, repeat step a. When a stage is reached such that no further replacements can be made, proceed to step c.

(c) If $V(999) = \infty$, then the set of flows currently listed in the table of link data constitutes a solution to the problem. If $V(999)$ is finite, then $V(999)$ represents the length of the shortest chain from 000 to 999 that consists entirely of unsaturated links, i.e., links whose flow, in the direction of the chain, is less than the link capacity. In the latter case, proceed to step d.

(d) Starting at node 999, "trace backward" along the approach link associated with 999 to its other node, say node i_1. From i_1 trace backward along the approach link associated with i_1 to a second node, say i_2. Continuing in this manner, at some stage s, $i_s = 000$ will be found, i.e., a chain that connects 000 and 999 will have been traced backward.

(e) For each link (i,j) in the chain found in step d, calculate $c(i,j) - f(i,j)$ if the orientation of this link in the chain agrees with that given in the link table. Calculate $c(i,j) + f(i,j)$ if the orientations are opposite. Let M denote the minimum of the quantities calculated.

(f) Adjust flows in the last column of the link table as follows: For each link in the chain found above, add or subtract M from the presently tabulated flow, according as the orientation of the link in this chain agrees with or differs from that given in the link table. If the adjusted flow in any link is now negative, change its sign and reverse the order of the two nodes in the table. (This is done merely to avoid the necessity of storing negative quantities in the table.)

(g) Record the chain 000, i_{s-1}, i_{s-2}, . . . , i_1, 999 found in this iteration of the procedure and also the associated flow M. The first and last nodes need not be recorded, since they are necessarily 000 and 999.

(h) Restore the labels of all nodes to their original values, erase all approach links, and return to step a.

After a finite number of chain flows has been found, a stage will be reached such that $V(999) = \infty$ in step c. When this occurs, the link flows tabulated in the link table constitute a solution to the problem, and the set of chain flows recorded in step g is a decomposition of the solution into flows along specific routes from origins to destinations.

Alternative Method of Solution. The algorithm just described was incorporated in a prototype network-analysis program and has yielded satisfactory routings in the theater situations to which it was applied. Although the procedure always determines a routing schedule that meets all the destination requirements when possible, it does not invariably find a solution that minimizes total ton-mileage. For this reason a revised algorithm was developed. This algorithm is very similar to the original one, consisting of a number of iterations of a labeling procedure, each of which produces one route. The principal difference is that instead of selecting at each stage the physically shortest unsaturated route from source to sink it selects a route that is "effectively" shortest, in a certain well-defined sense. A complete description of the revised algorithm appears in a separate publication.[2] That publication also contains a mathematical proof of the validity of the algorithm.

Complete Network-Analysis Procedure. The integrated procedure for finding rail and highway routes consists of four phases, each of which involves solution of a network subproblem of the type previously described.

(a) Assuming the basic network data are stored on magnetic tape, that portion of the tape file describing the rail network is read into fast-access computer storage. Any modifications of these data are made at this time. The origin data are then used to generate "origin links" of the form (000, i) in the manner described earlier. The capacity $c(000, i)$ is taken to be $C_i \cdot K$, where C_i is the capacity of port i, in terms of port workload, given by the input, and K is the ratio of LOC workload to port workload for the time period being analyzed. Similarly "destination links" are generated, for category 1 destinations only. The basic algorithm described earlier is then applied to the augmented network, and a series of rail routes from ports and beaches to category 1 depots is determined.

(b) After step a terminates (either because all requirements of category 1 depots have been met by rail movements or because bottlenecks prohibit further movements), the table of links is further augmented by destination links corresponding to the category 2 depots. The basic algorithm is applied again, and a set of rail routes terminating at category 2 depots is found.

TABLE 7

SUMMARY ROUTE OUTPUT

Mode[a]	Sequence no.	Origin	Destination	Flow, short tons/ day	Length, miles	Ton-miles, thous
1	001	2	6	1000	340	340
1	002	3	4	1200	100	120
1	003	3	6	500	120	60
2	001	1	2	1100	60	66
2	002	1	4	600	120	72

[a]1 denotes rail, 2 denotes highway.

(c) When no more rail routes to category 2 depots are possible, the table of links is augmented by destination links corresponding to category 3 depots, and more rail routes are found, if possible.

(d) That portion of the link table representing actual rail links is transferred back to magnetic tape in its final form (i.e., retaining the recorded total flow in each link, as well as its capacity and length). The origin and destination links are retained in fast-access storage and are augmented by destination links corresponding to category 4 depots. To these hypothetical links are added the links of the basic highway network file, modified by any network-change data that may have been prescribed. The basic algorithm is applied once more, and a set of highway routes is selected. This step terminates when all requirements have been met or when no unsaturated highway routes remain.

Program Output

Each time a route is selected in any of the four computational phases a punched card is produced containing the origin and destination nodes, route length, flow in tons per day, and ton mileage. It also contains a 1-digit mode identification and a 3-digit sequence number. Table 7 shows a sample listing of a few such cards.

To be able to trace the specific path of each route, a detailed listing is also produced (Table 8) that gives for each route the complete set of nodes that it contains.

After all routes are selected a listing is produced (Table 9) showing the final state of each rail and highway link. For each link the following are given: mode, nodes connected, capacity, total flow, residual or unused capacity (difference between original capacity and total flow), and total link ton-mileage. From this report all rail and highway bottlenecks can be identified. Also the residual capacity information forms the starting point for manual selection of alternative or additional routes, should these be required.

TABLE 8

DETAILED ROUTE OUTPUT

Mode	Sequence no.	Node sequence[a]							
1	001	17	14	128	104	112	6	—	—
1	002	102	116	42	50	58	63	4	12
1	003	102	116	37	6	—	—	—	—

[a]The first and last numbers in each line are the node numbers of an origin and destination respectively. If the number of nodes in a route exceeds the limitations of one line, trailer lines are required.

TABLE 9

FINAL STATE OF NETWORK

Mode	Nodes connected		Length, miles	Capacity	Flow, short tons/day	Residual capacity	Ton-miles, thous
1	2	16	27	4,000	0	4000	0
1	2	26	42	3,000	1000	2000	42
1	13	116	30	12,000	2500	9500	75

Special Feasibility Runs

Should computations terminate before all tonnage has been routed, several courses of action are open to the planner. If only a small amount of tonnage remains unrouted, he may be able to determine quickly one or more transshipment (rail and highway) routes to move the remaining tonnage. The output listing of unused link capabilities will facilitate these selections. However, if an appreciable tonnage cannot be moved by pure rail and highway movements, he may wish to determine the general feasibility of finding sufficient transshipment routes before spending time selecting specific routes. One way to establish the feasibility (or nonfeasibility) of using this program is outlined below.

The rail and highway links can be combined in a single network file, as though a single mode existed. Using this network, routes can be selected. Of course each route selected may now consist of a mixture of rail and highway links. From an operational point of view, some of the indicated transshipments may be altogether unreasonable. But such a run can establish whether or not it is possible to move the required tonnages over the surface LOC, for if this run also terminates before all tonnage has been moved, it can be concluded that it is definitely not feasible to schedule all movements without modified assumptions (e.g., adding more links or increasing the capacities of bottleneck links).

It is recognized that such a run would seldom be necessary and certainly does not constitute a standard component of the recommended planning procedure. However, this idea is intended to be suggestive of special-purpose runs that can be made with the basic program.

Programing Notes

The network utilization program must have the capability of handling networks having 600 links relative to each mode. It would be desirable to provide for 1000 links relative to each mode if storage space permits. The prototype 1103 A program conserved storage space (at the expense of operating speed) by packing several quantities in a 36-bit computer word. Specifically the length and capacity of a link and the two node numbers and flow were packed together. If this is done Table 5 requires 2N words of computer storage, where N is the number of links. Note that the rail and highway link tables do not have to be contained in fast-access storage simultaneously. However, if the program does not provide internal space for the combined tables, the capability to make special feasibility studies in the manner described earlier is lost for large networks.

Figure 16 shows a general flow chart for this program. Note that the sequence indicates that all input cards are read before any routes are determined even though some of the data are not required until the second, third, or fourth computational phase. This is suggested in order that any unacceptable input cards may be detected as early as possible in the run, minimizing wasted operating time.

The summary route data shown in Table 7 are punched in cards rather than being written as a printer tape file because of their role in the next computer program. This deck, when modified by the addition or substitution of cards representing routes selected by the planner, forms the principal input to that program.

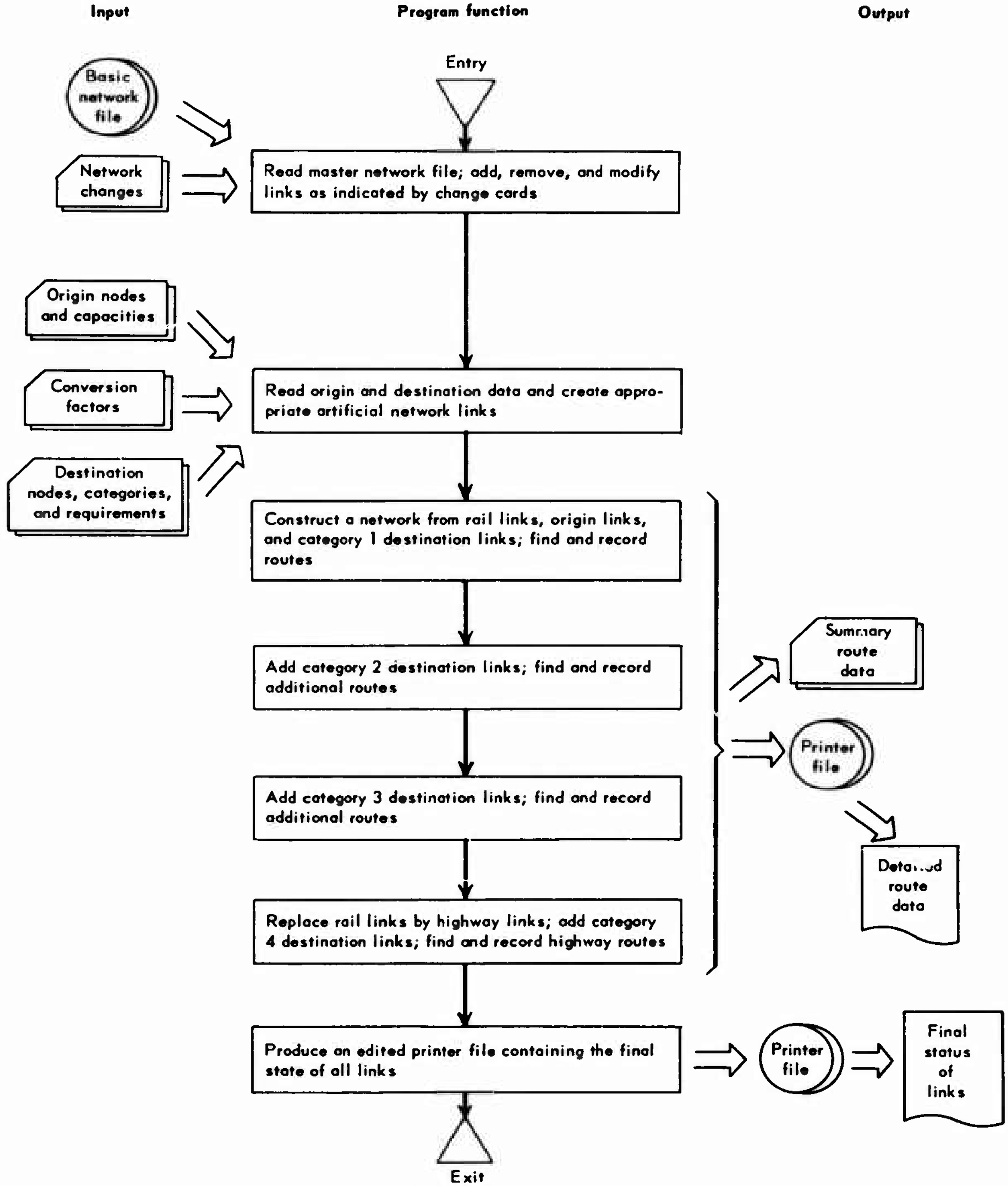

Fig. 16—General Flow Chart for Network Utilization Program

SUMMARIZATION OF ORIGIN AND LOC TONNAGES

The present computer program is by far the simplest one incorporated in the planning procedure, since its only function is to prepare three summaries of information previously generated. The summarization process was not made a part of the network utilization program for two reasons. First the planner should have the capability to use the computer for obtaining these summaries even in those cases where he chooses not to use the network utilization for the selection of routes. Second even when that program is used it is desirable that the routes be reviewed and modified if necessary before these reports are produced, since otherwise each report must be individually adjusted.

Program Function

This program produces the following three tabulations for each time period analyzed relative to network utilization:

(a) The total tonnage moving over the rail and highway LOC between a given origin and destination. This is the LOC workload report.

(b) The total tonnage discharged at each individual origin. This is the port workload report.

(c) The total tonnage cleared by TC from each origin. This is the port clearance report.

Program Input

LOC Tonnage by Route. The primary input to this program consists of the summary route deck of punched cards produced as output by the network utilization program or a comparable deck specially prepared if network utilization is manually determined. For each period analyzed there is a card for each rail and highway route specifying the origin and destination connected and the daily rate of tonnage. The cards produced by the network utilization program also indicate the mode, the route length, and route ton-mileage (see Table 7). However, this information is not utilized by the present program.

Tonnage Conversion Factors. In addition to LOC workload by route two conversion factors must be given for each period analyzed: the theater-wide ratio of LOC workload to port workload, and the theater-wide ratio of port clearance to port workload. These are furnished by the planner on Form 14J, shown in Fig. 15.

Computations and Output

The quantities appearing on the LOC workload report are obtained by summing all individual route tonnages for a fixed origin-destination combination. This is done for each meaningful origin-destination combination (i.e., so that at least one route between them was selected) and for all periods in which the network was analyzed. Figure 17 shows a format for this report.

The port workload report (Fig. 18) is obtained by further summarization of the LOC workload. For a given origin the LOC workload to all destinations is computed and then divided by the theater-wide ratio of LOC workload to port workload for the appropriate period.

The port clearance report is obtained by multiplying each port workload tonnage by a conversion factor, which is the theater-wide ratio of port clearance to port workload tonnages for the appropriate time period. The same format (Fig. 18) applies to both the port workload and clearance reports.

As in the case of other output reports described in this paper, the report formats shown are not mandatory. Other formats that exhibit the same information and are acceptable to the TC planner may be substituted, as programing considerations dictate.

LOC workload report (short tons/day)							
Origin no.	Destination no.	Period*					
		1	2	3	4	5	6
1	2						
1	7						
2	1						
2	3						
2	4						
3	2						

Fig. 17—LOC Workload Report Format

*Period numbers normally correspond to calendar quarters, since one month of each quarter is usually selected for LOC analysis.

Port workload report (short tons/day)						
Origin no.	Period					
	1	2	3	4	5	6
1						
2						
3						
4						
5						

Fig. 18—Port Workload Report Format

Class IV Requirements

In principle gross requirements R for a Class IV equipment item are based on the workload W divided by the rated capacity C of the equipment item and multiplied by a weighting factor F.

However, the time and distance factors peculiar to the situation must be introduced, and since it is transportation equipment in question, this can generally be done by multiplying W by the sum of time spent in travel and time spent loading and unloading (i.e., dividing rated capacity by this sum).

Finally it will generally be the case that some percentage less than 100 of the total workload is applicable to any particular item of equipment.

Accordingly in the present form of the procedure the following standard expression is used to translate workloads into gross Class IV requirements R for any item (with one exception, discussed below):

$$R = \frac{W\,p\,F(T + L)}{C} \qquad (5)$$

where W = workload, short tons per day, cars per day, etc.

p = fractional applicability of the workload to the particular item

F = contingency factor, i.e., a fractional weighting factor estimating the expected effect of certain contingencies on the rated capacity of the item (see further discussion in the text)

T = travel time, days, e.g., one day to destination, one day return yields $T = 2$

L = load/unload time, days, e.g., a train, including the boxcars, takes 2 days to load and make up and 2 to unload yielding $L = 4$

C = rated capacity of the particular item in units of the workload

The present procedure is built around this formula, which, however, is itself expected to evolve. For instance consider the factor F representing the expected effect on rated capacity of chance occurrences in the theater of operations. In the case of locomotives, for instance, F represents the effect of weather on hauling power. Table 10[7] lists the values F may assume in this case.* In the case of boxcars, because of maintenance the estimated availability of boxcars in actual operations is 80 percent, so that $F = 1.25$.

* The "weather factor" shown in Table 10 is $= {}^{1}/F$, i.e., the rated capacity is multiplied by the weather factor.

Now all these contingencies are susceptible of being evaluated in more precise terms, taking advantage of the capabilities of the computer. For instance the variations of weather could be taken into account in computing locomotive requirements. It is TC's intention to exploit such capabilities inherent in computer-assisted planning so that the complexity and variety of formulas for translating workloads to requirements may be expected to grow and hence to make continuing demands on program maintenance. Obviously this intended development must also be kept in mind during programing of the operational routines.

TABLE 10

EFFECT OF WEATHER ON HAULING POWER OF LOCOMOTIVES[7]

Most adverse temperature, °F	Loss in hauling power, %	Weather factor, %
> +32	0	100
+16 to +32	5	95
0 to +15	10	90
−1 to −10	15	85
−11 to −20	20	80
−21 to −25	25	75
−26 to −30	30	70
−31 to −35	45	65
−36 to −40	40	60
−41 to −45	45	55
−46 to −50	50	50

Source of Input Data

In applications the computer installation will look to the TC planner for the data from which to prepare the necessary computer inputs. In current practice these data are supplied on simple transmittal slips or forms illustrated below. It must be emphasized, however, that the forms shown are a preliminary design used in the latter phases of research when TC was producing studies with the help of prototype computer routines using ORO's scientific-type computer installation. In other words one of the first tasks in reducing the research results to operational procedures should be to redesign these forms and "engineer" them to the particular computer installation. They are presented here as preliminary suggestions for the forms designer. The main point to remember is that these "forms" do not function like the forms in a data-processing system. Functionally they are summary records of planners' decisions for transmittal to the computer installation; they should be kept simple, since the prime requirement is to facilitate—not complicate—the planner's task. The secondary requirement is to facilitate the task of the operator preparing punched cards or magnetic tape.

With these facts in mind it is believed that discussion and examples of the application of Eq. 5 in current practice will prove helpful in writing operational routines, in program maintenance, and of course in design of forms and procedures. In all such applications the data are currently supplied by the planner on TC Forms 14L, M, or Q (Figs. 19–21). Form 14L, Fig. 19 summarizes by route* the tonnage workload W—either dry-cargo or POL—and the route travel-time factor T.

Form 14M, Fig. 20 summarizes tonnages W by period to be used in computing requirements for switch engines. These workloads are broken down, as required for this purpose, by railhead, division terminal, or port;† within each of these categories dry-cargo tonnages are again separated from POL.

Finally Form 14Q, Fig. 21, transmits the travel time factor T for equipment not associated with rail, highway, or inland-waterway routes, such as materials handling equipment (MHE), and for each Class IV item, all the other factors needed to apply Eq. 5, viz., the contingency factor F; load/unload time L ; capacity C (of the item), and the percentage applicability of the workload p.

Specific examples of typical applications follow.

Rolling Fluid Transporters

Gross requirements for this item of equipment are based on POL movement per route in short tons per day W, obtained from the third column, relative to the first column, Form 14L, Fig. 19, route travel time T obtained from the fifth column of the same form; and from Form 14Q, Fig. 21, the contingency factor F from the second column; load/unload time L from the fourth column, capacity C (of the item) from the fifth column, and fractional applicability of the workload p from the sixth column. With these data, Eq. 5 is applied, and the result, rounded up, is the number of transporters required for a given route in a given period; the total over all routes is the period requirement. Table 11 summarizes the factors used, exhibiting where appropriate numerical values typical of those likely to occur in current planning.

Railway Dry-Cargo Cars

Gross requirements for this item of equipment are based on dry-cargo movement per route in short tons per day W, obtained from the fourth column, relative to the second column of Form 14L, Fig. 19; route travel time T from the fifth column of Fig. 19; and the contingency factor F from the second column, load/unload time L from the fourth column, capacity C (of the item) from the fifth column, and applicability of the workload p from the sixth column of Form 14Q, Fig. 21.

With these data as inputs, Eq. 5 is applied, yielding a result that when rounded up is the required number of dry-cargo railway cars of a particular type for a given route over a given period. Table 12 summarizes the application, showing typical factor values where possible.

*That is, separately for each rail and highway route developed by the network-analysis routines (see section "Utilization of Rail and Highway Networks," subsection "Computations").

†The basic tonnage workloads by route have, of course, been produced by computer at an earlier stage, but a planning stage has intervened, and it is the results of this intervening stage which the three forms under discussion summarize. A good example is the decisions that locate division points within routes, resulting in the breakdown of workloads given on Form 14M.

ROUTE DATA

	Highway	Rail	POL ST/Day	Dry Cargo ST/Day	tf
Total					

TCPLN Form 14 L, 7 Sep 60

Fig. 19—Input Form for Route Data

RAIL TONNAGE (ST/DAY)						
During Period	Railhead		Division Terminal		Port	
	DC	POL	DC	POL	DC	POL

TCPLN Form 14 M, 7 Sep 60

Fig. 20—Input Form for Rail Data

CLASS IV ITEMS	FACTORS				
	Contingency	Travel Time (Days)	Load-Unload (Days)	Capacity ST	% of Workload Handled

TCPLN Form 14 Q
7 Sep 60

Fig. 21—Input Form for Class IV Materiel Factors

The requirements for each type of car are summed over routes to obtain total period requirements for that type.

TABLE 11

ROLLING FLUID TRANSPORTERS—TYPICAL FACTOR VALUES

Factor	Value
W	Short tons of POL per day per highway route
p	1.0
T	10 days for 600-mile route[a]
L	2 days[b]
F	1.1[c]
C	3.2 short tons

[a]That is, (600 miles/120 miles/day) · 2, where 120 miles/day is the average rate of travel of a light truck company and the factor of 2 covers the return trip empty. In practice T will vary widely from this value, since the planner will very often disregard average rates and calculate the probable rate of movement for the particular route under the given conditions of the campaign. For short-haul routes the method of estimation varies slightly.

[b]Based on an estimated day to load the convoy and the same time to unload.

[c]Represents the estimated average effect of down time, maintenance, and related contingencies.

TABLE 12

RAILWAY DRY-CARGO CARS—TYPICAL FACTOR VALUES

Factor	Value
W	Short tons of dry cargo per day per rail route
p	Percent of car type[a]
T	2 days (per rail division)
L	4 days
F	1.1
C	20 short tons (per 40-ton car)

[a]The composition of military trains by car type, i.e., boxcars, flat cars, gondolas, etc., may vary with the situation. The planner determines p from his study of the situation. Note that if p_i designates the value for the i^{th} car type, necessarily

$$\sum_{i=1}^{n} p_i = 1,$$

where n is the number of car types.

Tank Cars

Gross requirements for this item reflect the tonnages of bulk POL to be moved, other than by pipeline, inland waterway, or highway. Again the requirements are computed by rail route, rounded up, and summed over routes to yield total period requirements.

The POL rail movements are supplied by the TC planner on Form 14L, Fig. 19, the third column relative to the route indicated in the second column and the rail travel time on the same form, the fifth column. As is standard F, L, C, p are supplied on Form 14Q, Fig. 21, the second, fourth, fifth, and sixth columns. Table 13 illustrates the factors commonly involved.

TABLE 13

TANK CARS—TYPICAL FACTOR VALUES

Factor	Value
W	Short tons of bulk POL per day per rail route
p	1.0
T	2 days (per rail division)
L	4 days
F	1.1
C	30 short tons (per 40-ton tank car)

TABLE 14

ROAD ENGINES—TYPICAL FACTOR VALUES

Factor	Value
W	Total cars of all types, dispatched from origin per day per route
p	1.0
T	2 days (per rail division)
L	0[a]
F	1.2[b]
C	20 cars

[a]Time for refueling, inspection, etc., is included in T.
[b]See FM 101-10.[8]

Road Engines

Gross requirements for road engines are based on the number of cars of all types to be hauled over the rail divisions.

The applicable number of cars W is derived from the data supplied on Form 14L, Fig. 19, the second, third, and fourth columns, in the following manner. In the second column each rail route is listed by its 4-digit identification number taken from the rail network-analysis printout* that the computer installation supplied to the planner at an earlier stage, as adjusted by the planner. The third and fourth columns list the corresponding average POL and dry-cargo tonnage moving daily. The workload W is simply the POL tonnage divided by 30 plus the dry-cargo tonnage divided by 20 (see values for C, Tables 13 and 14). A separate Form 14L will be supplied for that month in each quarter having the maximum port workload in the theater during that quarter.

*As emphasized above these details reflect the procedure using the research prototype computer routines. Changes in detail necessitating corresponding minor changes in forms and procedures are to be expected during development.

The route travel factor T, of course, comes from the fifth column of Fig. 19, and the factors p, L, F, and C from Form 14Q, Fig. 21.

As with other items the route requirements, rounded up, are summed over routes to produce total period requirements.

Table 14[8] illustrates the factors for road engines.

TABLE 15

SWITCH ENGINES—TYPICAL FACTOR VALUES

Factor	Dimension and typical value
$W(p_i)$	Number of cars yarded at port i
$W(r_k)$	Number of cars yarded at railhead k
$W(d_j)$	Number of cars interchanged at division terminal j
p	1.0
$T + L$	1.0[a]
F	1.2
$C(p) = C(r)$	33 cars per switch engine
$C(d)$	50 cars per switch engine

[a]That is, this factor is eliminated from Eq. 5.

Switch Engines

Gross requirements for this item are based on the number of cars to be handled at switching points, i.e., at ports, division terminals, and railheads, and hence essentially on daily tonnage movements. The data for computing workloads W are supplied on Form 14M, Fig. 20.

The first column in Fig. 20 specifies the period.* Each port, division terminal, and railhead in operation during a given period generates a separate line entry for that period under the appropriate column heading on Form 14M, (Fig. 20), with dry-cargo and POL tonnages separated. In other words letting p_i, d_j, r_k represent the ith port, jth division terminal, and kth railhead

$$W(p_i) = \frac{DC(p_i)}{20} + \frac{POL(p_i)}{30}$$ = number of cars yarded daily at p_i, as a function of the dry cargo and POL (POL_i) handled there

A similar expression yields the number of cars yarded at railheads as $W(r_k)$ and the number interchanged at division terminals as $W(d_j)$.

The remaining factors p, F, and C are supplied on Form 14Q, Fig. 21. (The factors T and L are eliminated since they enter the determination of C.) Typical factor values are shown in Table 15, with the item capacities associated with ports, division terminals, and railheads designated by $C(p)$, $C(d)$, and $C(r)$.

* Here "period" means that month in each calendar quarter in which tonnage moved reaches a maximum, i.e., requirements are computed so as to provide capability for handling the peak load anticipated in each quarter.

Requirements for any given period are the sum of requirements over all locations in operation at that period, as determined by reference to the first column, Form 14M (Fig. 20). Thus, letting

$$P_i = \frac{W(p_i)F}{C(p)},\ D_j = \frac{W(d_j)F}{C(d)},\ R_k = \frac{W(r_k)F}{C(r)}$$

each of these numbers is rounded off and they are then summed over all locations, so that

$$\text{period requirements} = \sum_{i=1}^{m} P_i + \sum_{j=1}^{n} D_j + \sum_{k=1}^{s} R_k$$

where m is the number of ports in the theater, n is the number of division terminals, and s is the number of railheads.

TABLE 16

EXAMPLE OF OUTPUT FOR CLASS IV MATERIEL

Materiel	Quarter						Peak requirements
	1	2	3	4	5	6	
LOCO, DE, 56½ IN GA, 60 TON, 0-4-4-0 WH, DS	2	0	0	0	0	0	2
LOCO, DE, 56½ IN GA, 120 TON, 0/6/6/0 WH, DS	6	4	0	0	0	0	10
RWY CAR, BOX 56½ IN GA, 50 TON, 8 WH, DS	52	3	4	0	0	0	59
RWY CAR, GON, LS 56½ IN GA, 40 TON, DS	64	4	5	0	0	0	73
RWY CAR, FLAT, 56½ IN GA, 40 TON, 8 WH, DS	57	4	4	0	0	0	65
RWY CAR, TANK, PET, 56½ IN GA, 10,000 GAL, 8 WH, DS	114	167	60	0	0	0	341
TRANSPORTER, LIQUID ROLLING WHL, 1,000 GAL, T3	227	252	394	0	0	0	873

Printout of Class IV Requirements

Table 16 is a sample of the computer printout, using the prototype routines and ORO's computer, of gross Class IV requirements for several of the items of equipment just discussed. This is in the format currently required by TC and DCSLOG.

QMC MHE

TC requirements for Class IV MHE are generated by port operations. Two methods of allocation are practiced: (a) on the basis of the type of operation* and (b) on the basis of the workload. The computations for the first method of allocation are trivial and are made directly by the planner. The computer installation is concerned only with the second method of allocation.

Each item of MHE handles only a part of the total dry-cargo workload,† at a single location, and the percentage that it handles may vary for different concepts of operation. These percentages p are given in the sixth column, Form 14Q (Fig. 21). If p varies throughout the campaign for any item, this fact is so noted on the form.

The other factors (F, T, L, and C) required for application of Eq. 1 to each MHE item are also given on Form 14Q (Fig. 21), and are held constant throughout the computations.

Requirements are computed for each item for each period for each port. The workload W for each is obtained from the first and second columns of Form 14R, Fig. 22. Port designation numbers are preceded by the letter P‡, and the tonnages for each P are given in the second column. There is a separate Form 14R for each period.

A table of typical factor values for MHE is not attempted because of the wide variability of these values that depend on assumptions about port facilities, size of the workload, concept of operation, and particular item.

CONEX Containers

The Joint CONEX Container Agency (JCCA) is responsible for the computation of requirements for this item (the one item, mentioned above, to which Eq. 5 does not apply). CONEX containers are loaded in CONUS, shipped to the theater, where they may remain up to 75 days, and are then returned to CONUS for reloading. Returned containers are applied against gross requirements to obtain the net requirements. JCCA computes this cyclic movement by days, for the entire campaign, to achieve as much accuracy as possible in assessing requirements.

A prototype program for requirements computations to duplicate the JCCA manual computations was compiled and is shown in Fig. 23. Calculations of container requirements were made in parallel with JCCA for SL 7(63), SL 4 (62-A), and SL 2(66-G) with negligible differences between manual and computer results.§

A very important aspect of the JCCA procedure is the assumption that requirements start a definite time before D-day, taken to be $D - (T_1 + L_1)$ where T_1 is the one-way travel time from CONUS to the theater and L_1 is the loading and handling time within CONUS prior to shipment. The theater workload on D day is used to compute requirements for $D - (T_1 + L_1)$ and this offset interval is held constant throughout the campaign.

*For example, drive and driven conveyor sections are frequently allocated as one each per troop-disembarkation port regardless of the extent of the operation. This computation is made by the planner.

†POL is at present discharged by QMC, and TC has no requirement for MHE for this purpose.

‡Beach designation numbers are preceded by the letter B. No Class IV MHE is required for beaches.

§Entirely due to rounding off errors.

Period No. ________

Adjusted P/B Wkld		Type, Cargo Discharge (ST/Day)						IWW (ST/Day)		
P/B	Workload	Offshore Hvy Boat	Instream		Alongside	Amphib.	Shore	Origin P/B	Destin. P/B	% Towed
			Lt. Boat	Med. Boat						
							TOTAL			

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Fig. 22—Input Form for Cargo Handling and Discharge

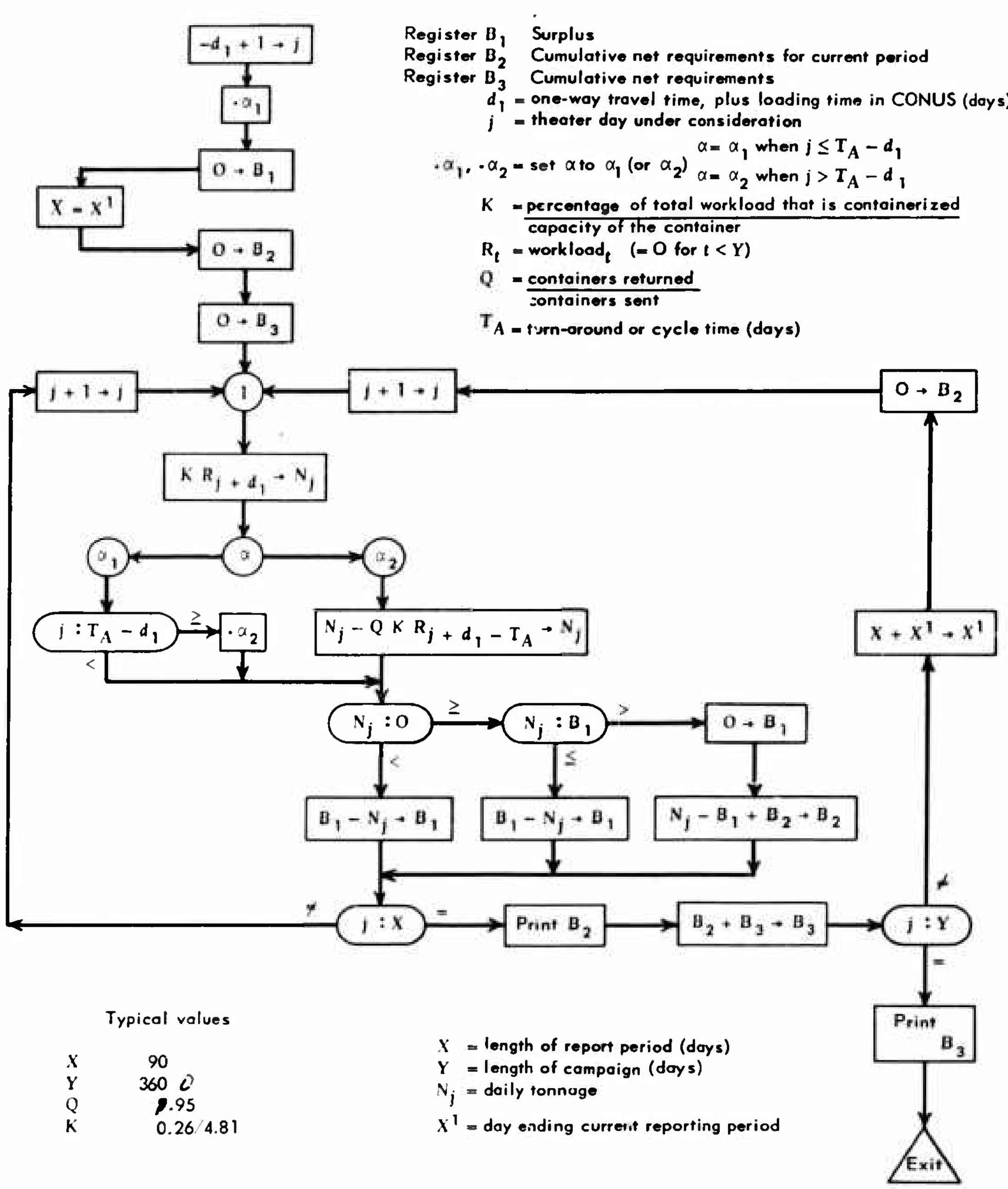

Fig. 23—Prototype Program for CONEX Container Requirements

The first return of containers to CONUS is on day

$$D + T_2 + L_2 + L_3$$

where $T_2 = T_1$ is the one-way travel time between CONUS and the theater, L_2 is cyclic time in the theater (from port to destination and return to port), and L_3 is CONUS time from port to depot for reloading. The turn-around time $(TA) = T_1 + T_2 + L_1 + L_2 + L_3$.

TABLE 17

DAILY TIME TABLE, CONTAINER ROUTING

CONUS depot	CONUS port	Theater port	Theater port	CONUS port	CONUS depot
$D-(T_1+L_1)$	$D-T_1$	D	$D+L_2$	$D+T_2+L_2$	$D+T_2+L_2+L_3$
$D-(T_1+L_1)+1$	$D-T_1+1$	$D+1$	$D+L_2+1$	$D+T_2+L_2+1$	$D+T_2+L_2+L_3+1$
$D-(T_1+L_1)+2$	$D-T_1+2$	$D+2$	$D+L_2+2$	$D+T_2+L_2+2$	$D+T_2+L_2+L_3+2$
↕	↕	↕	↕	↕	↕
D	$D+L_1$	$D+T_1+L_1$	$D+T_1+L_1+L_2$	$D+T_A-L_3$	$D+T_A$
↕	↕	↕	↕	↕	↕
$D+(360-T_A)+L_1$	$D+(360-T_A)+L_1$	$D+(360-T_A)+T_1+L_1$	$D+360-T_2-L_3$	$D+360-L_3$	$D+360$

This first return to CONUS depot is the quantity computed for day $D-(T_1 + L_1)$ minus a suitable attrition (usually taken as 5 percent). Table 17 illustrates the progressive procedure. (This table shows the first return to be on $D + T_2 + L_2 + L_3$ or $D + T_A - T_1 - L_1$.) For example, let $T_1 = 7$, $L_1 = 30$, $T_2 = 7$, $L_2 = 75$, $L_3 = 15$; $T_A = 134$. The computations for D-day requirements start on $D - 38$. These containers arrive at CONUS depot on $D + 97$. The returned containers are applied to the gross requirements existing in CONUS depot on $D + 97$, for the theater workload 37 days later, or $D + 134$.

	Period						Peak requirements
	1	2	3	4	5	6	
CONEX containers	xxxx	xxxx	xxxx	xxx	xx	x	xxxx

Fig. 24—Example of Output—CONEX Containers

The program takes cognizance of an excess of returned containers over the daily requirement, and the printout will be 0 when such excess exists, indicating the requirements are fully satisfied by the surplus.

For each reporting period the cumulative requirements for that period are printed out (print B2). At the expiration of the campaign, the peak requirements (total) are printed out (print B3). The format of the printout is immaterial, but the information shown in the example presented in Fig. 24 must appear.

Troop-Unit Requirements

The final output of the computer-assisted programs is the listing of the troop-unit requirements and a summation of troop strengths. At least two methods of computing the requirements for troop units are open to the planner. Method 1 gives the translation of workloads and work units into troop units in accordance with the authorized TOEs, and includes cellular types of composites for fractional workloads; method 2 is an approximation that rounds all fractional workloads and reduces the cellular requirements to a minimum. The computer installation is advised which method will be used in the computations for a specific t-annex.

The rules for computing TC TOE requirements under both methods have been set down into 16 sections, each of which is organized into a data sheet. These data sheets are found in App A. Each sheet gives the input required, computations involved, and output produced for certain of the TOEs. Methods 1 and 2 are shown near Tables A2 to A17, where applicable, and the balance of the computations is identical for both methods. The sequence of the data sheets is important, for in some cases the input to one sheet depends on output from preceding ones.

Many of the computations are of the following form:

$$I/D = Q + R/D$$

where I is an input quantity (e.g., a tonnage), D is a divisor reflecting the capability of a major TOE unit, Q is the resulting quotient, and R the remainder. Q is taken to be the number of major TOE units required, and R is used to enter a "remainder" table that specifies various combinations of cells (organizations smaller and less significant than major units) required to handle the residual quantity R. These "remainder" tables also indicate the troop strength for each combination of cells.

Table A1 gives a complete cross-reference list between codes and the units and cells designated. Thus TS' is the designation for a terminal service company and FB denotes a utility boat crew. Table A1 also gives the appropriate TOE number and strength of each entry. The TOE units and cells are coded in the data sheets, which give the computations required for an arbitrary time period (one month). To obtain phased requirements each step must be repeated for the peak month of each quarter.

Figures 22, 25, 26, and 27 are the input forms related to the computations shown in App A, and Tables 18 and 19 show samples of the output report.

The four input forms complete the data necessary for the computation of troop-unit requirements. Form 14N, Fig. 25, is self-explanatory, and the data given are substituted directly into the formulas where they are called for. Form 14O, Fig. 26, is used only when inland waterways are to be included in the transport net. The form identifies the route by origin and destination and the "days of dispatch," or number of days in a complete load-unload-travel cycle.* Form 14P, Fig. 27, is used by the planner to compute type of highway

*Inland waterways operation is performed with cellular-type units. The equipment used is organically assigned so that the input for personnel requirement computations resembles the input for materiel requirements computations.

MISCELLANEOUS								
During Period	tt	s	bg	c	fa	Arctic Only		hm
						id	cd	

LEGEND - tt - Total number of troops in theater requiring heavy truck lift.
s - Total number of COMZ sections.
bg - Total number of Rifle Cos. in Inf. Div. battle groups.
c - Total number of corps.
fa - Total number of field armies.
id - Total number of Inf. Training Divs (Arctic Only)
cd - Total number of combat division (Arctic Only)
hm - Total number of miles used, in highway net.

TCPLN Form 14 N, 7 Sep 60

Fig. 25—Input Form for Miscellaneous Data

INLAND WATERWAYS		
P/B Origin	P/B Destination	Days of Dispatch

TCPLN Form 14 O
7 Sep 60

Fig. 26—Input Form for Inland Waterways Route Data

HIGHWAY (TON MILES)					
During Period	Dry Cargo				POL
	Total	% Off Road	Total Off Road	Total On Road	Total

TCPLN Fo m 14 P
7 Sep 60

Fig. 27—Input Form for Highway Route Data

operations, and the first and second columns contain his intermediate data, not needed by the computer installation. Form 14R, Fig. 22, contains the data to be used in the computation of marine and terminal units. The tonnage breakdown is furnished by the planner. When a column is left blank, the particular operation it represents will not be performed and the corresponding formulas are zeroed out. A separate form is usel for each selected period (usually the peak month in a quarter). The last three columns on Form 14R (Fig. 22) are used only when inland waterways are used in the operation. The column headed

TABLE 18

EXAMPLE OF INTERIM OUTPUT FOR TROOP UNITS, METHOD 1[a]

Unit or cell[b]	Period			
	1	2	3	4
TS'	10	12	15	20
TS'_R	1	0	—	0
AA	1	6	2	5
AC	0	1	0	1
CA	1	1	1	1
CB	0	7	3	5
CC	0	1	0	0
JA	0	2	0	1
JB	1	5	2	4
JC/JE	2	12	4	10
JF	0	1	0	1
JG	0	1	0	1
JI	2	12	4	10
Strength (cells only)	44	279	85	234

[a]A similar output form, with appropriate troop-unit types, appears for each data sheet in App A. From the printouts of Method 1, the planner will derive a sheet similar to Table 20.

[b]Taken from section "Data Sheet 1."

"Shore" includes discharge either to riparian (river) or littoral (sea) shores, and the computer installation may be requested by the planner to keep these computations separate because of the existence of extreme conditions at certain discharge areas. The request will be documented by Form 14R and the desired separation will be clearly indicated in the eighth column and, as to locations, in the first column.

After all TOE requirements for a period have been computed, the total TC troop strength is computed by merely multiplying the number of each type of unit required by the unit strength given in Table A1 and by summing over all units. The total strength for each quarter appears in Table 20. Table 20 is an example of output of the Summary of Personnel Requirements, which gives a breakdown between combat and combat-support TC troops. In this connection combat strength refers to nondivisional combat units. Appendix A generates nondivisional requirements for six such units: TC', TC'_R, LH', LH'_R,

TABLE 19

EXAMPLE OF COMPLETED OUTPUT FOR TROOP UNITS, METHOD 2

Unit	Designation[a]	Date	Toe no.	Unit strength	Quarter 1	2	3	4	5	6
BN	TRANS ACFT HHD	10/31/58	55-056D	72	0	1	1	1	1	1
CO	LT HCPTR	3/12/56	55-057C	147	1	2	2	2	2	2
CO	TRANS ACFT HM+S(-)	4/ 8/55	55-458R	30	0	1	1	1	1	1
CO	MED HCPTR	11/ /58	55-158T	178	0	2	2	2	2	2
DET	C HCPTR FM	4/22/55	55-500R	55	1	2	2	2	2	2
DET	A ACFT REP	7/24/58	55-510T	82	0	2	2	2	2	2
COMD	TERMINAL A HHC	11/18/58	55-131D	131	1	1	1	1	1	1
BN	TRUCK HHC	11/10/58	55-16D	47	2	3	4	3	2	2
BN	TERM HHD	2/ 3/58	55-116D	56	2	2	2	2	2	2
CO	LT TRK 5T TYPE A	9/23/57	55-17D	176	10	12	7	12	10	10
CO	LT TRK 5T TYPE B	9/23/57	55-17D	73	1	1	1	1	1	1
CO	TRANS SLED	--	55-38T	109	0	2	2	2	2	2
CO	STAGING TYPE B	8/12/55	55-147C	23	1	1	1	1	1	1
CO	TERM SVC TYPE A	4/ 8/55	55-117R	331	3	3	3	3	3	3
CO	TERM SVC TYPE B	4/ 8/55	55-117R	113	2	2	2	2	2	2
CO	RAY ENGR TYPE B	1/11/54	55-227B	80	0	2	2	2	2	2
TM	AB PLAT HQ SEP	4/22/55	55-500R	4	2	2	2	2	2	2
TM	FF PATROL BOAT CREW	4/22/55	55-500R	3	3	3	3	3	3	3
TM	FN 100-FT TUG CREW	4/22/55	55-500R	16	2	2	2	2	2	2
TM	ID FLTG CRAFT M+R	4/22/55	55-500R	30	1	1	1	1	1	1
TM	LA MVMT CONT	4/22/55	55-500R	6	2	2	2	2	2	2
TM	LB MVMT CONT	4/22/55	55-500R	6	2	2	2	2	2	2
TM	LC MVMT CONT	4/22/55	55-500R	6	4	4	4	4	4	4
DET	HA TRANS INTEL	10/15/57	55-500R(C3)	12	1	1	1	1	1	1
DET	HB TRANS INTEL	10/15/57	55-500R(C3)	14	1	1	1	1	1	1
CO	TRANS (TAC CARR)	6/10/56	55-27C	184	2	2	2	2	2	2

[a]Abbreviations differ from authorized abbreviations because of space limitation.

MH' , and MH'_R. The strength of these units times the corresponding numbers required gives the combat strength. Total TC troop strength minus combat strength yields TC noncombat troop strength. Civilian strengths shown are not determined by the computer program.

Under method 2 the fraction R/C (where C is the unit work capacity) is rounded, but otherwise the two methods are the same.

No prototype program was prepared by the research team for the selection at either Class IV or TOEs.

TABLE 20

EXAMPLE OF OUTPUT FOR SUMMARY OF PERSONNEL REQUIREMENTS

Quarter	Combat		Combat support		Total	
	Military	Nonmilitary	Military	Nonmilitary	Military	Nonmilitary
1	515	—	3620	607	4135	607
2	1090	—	4646	807	5736	807
3	1090	—	5573	807	6663	807
4	1090	—	4646	807	5736	807
5	1090	—	4247	807	5337	807
6	1090	—	4247	807	5337	807

[a]Requirements are shown cumulatively for troops in place and operational as of end of period for which shown.

The printout of method 1 for TOEs is detailed and is intended to furnish the maximum amount of information for planner analysis. It is illustrated by the following example:

Assume 10 ports in use. It is necessary to select terminal service units from rules in section "Data Sheet 1." In the usual case the network analysis allocates total port workloads that are increments of daily average ship discharge (720 short tons/day) plus a fraction. Method 1 rules generate a composite (cellular) unit for these fractional loads. Follow this procedure for each time period. Assume four reporting periods for illustration. The printout then takes the form shown in Table 19.

Composite units are generated only: (a) where remainder tables are applicable under method 1; and (b) for augmentation tables under both methods.

Storage of rules and tables is to be predicated on the necessity for periodic maintenance and change. New units will be added to the data sheets, and some deletion may be expected. Quantities given in the denominators of selection rules are also subject to change, and the rules may increase or decrease in number as adjustments are made in the TOEs (see App A).

Appendix A

Troop-Unit Requirements Data

TABLES

TABLE A1

TC TROOP-UNIT CODES AND STRENGTHS

Code	Designation	TOE	Strength
AA	Plat HQ, Comp	55–500	2
AB	Plat HQ, Sep	55–500	4
AC	Co HQ	55–500	8
AD	Bn HQ	55–500	18
AE	Gp HQ	55–500	22
BA	Sup Det	55–500	2
BB	LCL Frt Team	55–500	5
BC	Sup Det	55–500	3
BD	LCL Frt Team	55–500	9
BE	Whse Team	55–500	24
BF	Whse Team	55–500	42
CA	Unit Mess	29–500	4
CB	Mess Aug	29–500	1
CC	Mess Aug	29–500	1
DA	Wh Veh Mech	29–500	1
DE	Wh Veh Mech	29–500	1
DG	Wh Veh Mech Sr	29–500	1
DI	Mtr Maint Sgt	29–500	1
EA	Amb Tn Maint Crew	55–500	3
EB	Ry Sta Det	55–500	3
EC	Ry Term Det	55–500	12
ED	Diesel Eng Loco Maint Crew	55–500	17
EE	Ry Sec Crew	55–500	14
EF	Steam Loco Maint Crew	55–500	16
EG	Ry Car Rep Crew	55–500	17
EH	Amb Tn Maint Sec	55–500	19
EI	Ry Sig and Comm Maint Crew	55–500	21
EJ	Diesel-electric Loco Maint Crew	55–500	30
EK	Ry Yard Op Crew	55–500	26
EL	Bridge and Building Maint Crew	55–500	26
EM	Steam Loco Maint Crew	55–500	29
EN	Ry Car Rep Crew	55–500	28
EC	Ry Tn Op Sect	55–500	32
EP	Ry Workshop Mbl	55–500	53
EQ	Ry Maint-of-Way Crew	55–500	61
FA	Prop Unit Crew	55–500	1
FB	Util Bt Crew	55–500	2
FC	Dry Cgo Barge Crew	55–500	2
FD	Liq Cgo Barge Crew	55–500	4
FE	Gas Barge Crew	55–500	5
FF	Ptl Bt Crew	55–500	3
FG	45-ft Tug Crew	55–500	5
FH	Reefer Barge (SP) Crew	55–500	6
FI	65-ft Pax and Cgo Bt Crew	55–500	5
FJ	65-ft Tug Crew	55–500	7
FK	Fltg Crane (60 Ton) Crew	55–500	10
FL	Fltg Crane (100 Ton) Crew	55–500	14
FM	Dry and Liq Cgo Barge (SP) Crew	55–500	24
FN	100-ft Tug Crew	55–500	16
FO	Reefer Barge (SP) Crew	55–500	28
FP	126-ft Ocean-going Tug Crew	55–500	18

TABLE A1 (continued)

Code[a]	Designation	TOE	Strength
FQ	86-ft Tug Crew	55–500	12
FR	72-ft Tug Crew	55–500	9
FS	BARC Op and Maint	55–500	51
GA	Car Sqd	55–500	12
GB	Bus Sqd	55–500	12
GC	Hv Trk Sqd	55–500	12
GD	Lt Trk Sqd	55–500	16
GE	Med Trk Sqd	55–500	16
GF	Tlr Trf Pt	55–500	16
GG	Hway Reg Pt	55–500	8
HA	Intel-Coll	55–500	12
HB	Intel-Rsch	55–500	14
HC	Intel-Aug	55–500	3
IA	Diver Team	55–500	7
IB	Fltg Craft Maint Team	55–500	8
IC	Fltg Craft Rep Team	55–500	13
ID	Fltg Craft Maint and Rep Team	55–500	30
IE	Term Fltg Craft Maint and Rep Team	55–500	84
IF	Rad and Radar Maint Team	55–500	2
JA	Maint Sec	55–500	2
JB	Crane Op Sec	55–500	2
JC	Mat Hdlg, Lt	55–500	2
JD	Term Contract Supv Det	55–500	8
JE	Mat Hdlg, HV	55–500	8
JF	Stev Gear and Eqp Sec	55–500	8
JG	Cgo Docu Sec	55–500	9
JH	Trk Sqd, Amph	55–500	13
JI	Cgo Hdlg Sec	55–500	16
KA	Hel Team, Lt Cgo	55–500	8
KB	Hel Team, Med Cgo	55–500	10
KC	A Acft Rep	55–500	23
KD	Cgo Hel Fld Maint Team	55–500	28
LA	Mov Con	55–500	6
LB	Mov Con	55–500	6
LC	Mov Con	55–500	6
LD	Mov Con	55–500	5
LE	Mov Con	55–500	5
LF	Mov Con	55–500	35
T^x	HQ and HQ Co Hway Trans Comd	55–11C	124
T^x_R	HQ and HQ Co Hway Trans Comd, Red	55–11C	105
T'''	HQ and HQ Det Trk Gp	55–12D	61
T'''_R	HQ and HQ Det Trk Gp, Red	55–12D	49
T''	HQ and HQ Det Trk Bn	55–16D	47
T''_R	HQ and HQ Det Trk Bn, Red	55–16D	37
LT'	Lt Trk Co	55–17D	168
LT'_R	Lt Trk Co, Red	55–17D	102
MT'	Med Trk Co	55–18D	181
MT'_R	Med Trk Co, Red	55–18D	114
C'	Trans Car Co	55–19D	111
C'_R	Trans Car Co, Red	55–19D	75
CC'	Trans Cgo Car Co	55–27C	184
CC'_R	Trans Cgo Car Co, Red	55–27C	134

Table A1 (continued)

Code[a]	Designation	TOE	Strength
HT'	Trans HV Trk Co	55–28C	165
HT'_R	Trans HV Trk Co, Red	55–28C	116
DA'''	Drive-away Plat (Aug)	55–28C	51
DA'''_R	Drive-away Plat (Aug), Red	55–28C	36
SL'	Trans Sled Co	55–38T	109
SL'_R	Trans Sled Co, Red	55–38T	84
TC''	HQ and HQ Det Tac Car Bn	55–46D	55
TC''_R	HQ and HQ Det Tac Car Bn, Red	55–46D	44
TC'	Tac Car Co	55–47D	180
TC'_R	Tac Car Co, Red	55–47D	120
TA''	HQ and HQ Det Trans Acft Bn	55–56D	72
TA''_R	HQ and HQ Det Trans Acft Bn, Red	55–56D	48
LH'	Lt Hel Co	55–57D	147
LH'_R	Lt Hel Co, Red	55–57D	113
MH'	Med Hel Co	55–58T	178
MH'_R	Med Hel Co, Red	55–58T	130
IDT''	Inf Div Trans Bn	55–75D	462
IDT''_R	Inf Div Trans Bn, Red	55–75D	380
IDT'	HQ and HQ Co Inf Div Trans Bn	55–76D	122
IDT'_R	HQ and HQ Co Inf Div Trans Bn, Red	55–76D	111
$IDTT'$	Inf Div Trans Bn Trk Trans Co	55–77D	156
$IDTT'_R$	Inf Div Trans Bn Trk Trans Co, Red	55–77D	111
$IDTA'$	Inf Div Trans Bn Armd Car Co	55–78D	92
$IDTA'_R$	Inf Div Trans Bn Armd Car Co, Red	55–78D	79
$IAMD''$	Inf Div Trans Acft Maint Det	55–79D	59
$IAMD''_R$	Inf Div Trans Acft Maint Det, Red	55–79D	43
$AAMD''$	Armd Div Trans Acft Maint Det	55–79D	64
$AAMD''_R$	Armd Div Trans Acft Maint Det, Red	55–79D	47
TC'''_C	HQ and HQ Co Term Comd C	55–111D	303
TC'''_{CR}	HQ and HQ Co Term Comd C, Red	55–111D	236
TS''	HQ and HQ Det Term Bn	55–116D	56
TS''_R	HQ and HQ Det Term Bn, Red	55–116D	46
TS'	Term Svc Co	55–117D	331
TS'_R	Term Svc Co, Red	55–117D	175
TC'''_B	HQ and HQ Co Term Comd B	55–121D	187
TC'''_{BR}	HQ and HQ Co Term Comd B, Red	55–121D	136
B''	HQ and HQ Co Trans Bt Bn	55–126D	79
B''_R	HQ and HQ Co Trans Bt Bn, Red	55–126D	58
LB'	Trans Lt Bt Co	55–127D	293
LB'_R	Trans Lt Bt Co, Red	55–127D	172
MB'	Trans Med Bt Co	55–128D	206
MB'_R	Trans Med Bt Co, Red	55–128D	145
HB'	Trans HV Bt Co	55–129D	171
HB'_R	Trans HV Bt Co, Red	55–129D	121
TC'''_A	HQ and HQ Co Term Comd A	55–131D	131
TC'''_{AR}	HQ and HQ Co Term Comd A, Red	55–131D	98
AT'	Trans Amph Trk Co	55–137C	194
AT'_R	Trans Amph Trk Co, Red	55–137C	132

TABLE A1 (continued)

Code[a]	Designation	TOE	Strength
SA'	Trans STGAR Co	55–147C	91
SA'_R	Trans STGAR Co, Red	55–147C	51
FCM'	Fltg Craft Dep Maint Co	55–157D	204
FCM'_R	Fltg Craft Dep Maint Co, Red	55–157D	166
RS^{xx}	GHQ Trans Ry Svc	55–201R	201
RG'''	HQ and HQ Co Ry Gp	55–202D	101
RG'''_R	HQ and HQ Co Ry Gp, Red	55–202D	79
EP'	Elec Power Xmsn Co	55–217R	194
EP'_R	Elec Power Xmsn Co, Red	55–217R	146
RO''	Trans Ry Op Bn	55–225R	823
RO''_R	Trans Ry Op Bn, Red	55–225R	625
RE'	Ry Engr Co	55–227R	251
RE'_R	Ry Engr Co, Red	55–227R	185
RS''	Trans Ry Shop Bn	55–235R	660
RS''_R	Trans Ry Shop Bn, Red	55–235R	518
D'	Trans Dep Co	55–260C	116
D'_R	Trans Dep Co, Red	55–260C	85
RC^x	HQ and HQ Co Trans Ry Comd	55–302D	139
RC^x_R	HQ and HQ Co Trans Ry Comd, Red	55–302D	111
AM''	HQ and HQ Det Trans A Acft Maint Bn	55–456R	33
AM''_R	HQ and HQ Det Trans A Acft Maint Bn, Red	55–456R	28
AAM'	Trans Acft DS Co	55–457R	156
AAM'_R	Trans Acft DS Co, Red	55–457R	130
AMS'	Trans A Acft Maint and Sup Co	55–458R	168
AMS'_R	Trans A Acft Maint and Sup Co, Red	55–458R	119
$AMS^{\cdot}$	Trans A Acft Maint and Sup Co (Aug)	55–458R	38
BM'	Trans Bt Maint Co	55–557R	146
BM'_R	Trans Bt Maint Co, Red	55–557R	102

[a]Superscripts denote the following organizational levels:

$\cdot$ Squad.	$'$ Company.	^{x} Command.
$\cdot\cdot$ Section.	$''$ Battalion.	^{xx} Division.
$\cdot\cdot\cdot$ Platoon.	$'''$ Group.	

Subscript R denotes reduced units.

DATA SHEET 1, TERMINAL UNITS

Terminal Service Companies

(a) Input. Workloads at ports and at beaches separately, short tons per day.

(b) Output. TS', TS'_R, AA, AC, CA, CB, CC, JA, JB, JC, JF, JG, JI.

(c) Computations.

$$\text{Method 1:}\quad \frac{\text{Total port workload + total beach workload}}{720} = Q + (R\ 720)$$

$$\text{Method 2:}\quad \frac{\text{Total port workload + total beach workload}}{720} = Q \text{ (round up)}$$

Q_i = number of TS' in theater.
Use R_i to enter Table A2.

TABLE A2

TERMINAL-SERVICE-UNITS DATA[a]

Range of R		Major units		55–500 cells								29–500 cells			Strength
From	To	TS'_R	TS'	AA	AC	JA	JB	JC/JE[b]	JF	JG	JI	CA	CB	CC	
1	25	—	—	—	—	—	—	—	—	—	—	—	—	—	0
26	75	—	—	—	—	—	—	1	—	—	1	—	—	—	18
76	125	—	—	1	—	—	1	2	—	—	2	1	—	—	44
126	175	—	—	1	—	—	1	3	—	—	3	1	1	—	63
176	225	—	—	2	—	—	2	4	—	—	4	1	1	—	85
226	275	—	—	2	1	—	2	5	—	—	5	1	3	—	113
276	325	—	—	3	1	1	2	6	—	1	6	1	3	—	144
326	375	1	—	—	—	—	—	—	—	—	—	—	—	—	175
376	425	—	—	4	1	1	3	8	—	1	8	1	4	—	185
426	475	—	—	4	1	1	4	9	1	1	9	1	5	—	214
476	525	—	—	5	1	1	4	10	1	1	10	1	5	—	234
526	575	—	—	5	1	1	4	11	1	1	11	1	5	—	252
575	625	—	—	6	1	2	5	12	1	1	12	1	7	1	279
626	675	—	—	6	1	2	5	13	1	1	13	1	7	1	297
676	719	—	1	—	—	—	—	—	—	—	—	—	—	—	331

[a]The total numbers of units of each type must be kept separately for ports and beaches, because of their later use in Data Sheet 5.
[b]Use JC for ports, JE for beaches.

DATA SHEET 2, TERMINAL UNITS

Staging-Area Companies

(a) Input. US troop increment during the month.
(b) Output. SA' and SA'_R.
(c) Computations.

Troop increment/10800 = Q + (R/10800)

Q = number of SA'.
Use R to enter Table A3.

TABLE A3

STAGING-AREA-UNITS DATA

Range of R		Units		Strength
From	To	SA'_R	SA'	
1	2700	—	—	0
2701	5400	1	—	51
5401	10799	—	1	91

TABLE A4

DEPOT-UNITS DATA

Range of R		55–500		29–500	Major units		Strength
From	To	BE	BF	CB	D'_R	D'	
0	340	—	—	—	—	—	0
341	1030	1	—	1	—	—	25
1031	1715	—	1	1	—	—	43
1716	2400	—	—	—	1	—	78
2401	2999	—	—	—	—	1	116

DATA SHEET 3, TERMINAL UNITS

Depot Companies

(a) Input. Short tons of TC materiel supplied during month (approximately 0.002 times monthly theater tonnage).[4]
(b) Output. D', D'_R, BE, BF, CB.
(c) Computations.

Method 1: TC tons/3000 = Q + (R/3000)

Method 2: TC tons/3000 = Q (round up)

Q = number of D'.
Use R to enter Table A4.

Transportation Boat Companies

(a) Input. For each port or beach the discharge rates shown in Table A5 hold, when applicable.

There is optional choice of one of two remainder tables in step (3) below. The planner will designate the option.

(b) Output. AT', AT'_R, HB', HB'_R, LB', LB'_R, MB', MB'_R, FA, FC, FF, FJ, FK, FS, JE, JH.

(c) Computations.

(1) $op/1440 = Q_a + (R_a/1440)$
Q_a = number of HB'.
Use R_a to enter Table A6.

TABLE A5

TRANSPORTATION-BOAT-UNITS DATA. A

Item	Symbol
Short tons/day discharged offshore at a port	*op*
Short tons/day discharged instream at a port	*ip*
Short tons/day discharged alongside at a port	*ap*
Short tons/day discharged amphibiously at a beach	*ab*
Short tons/day shore discharge at a beach	*rb*
Total short tons/day moved by *IWW*	*IWW*
IWW days of dispatch	DD
Total short tons/day moved by non-propelled barge requiring self-propulsion	*sp*

TABLE A6

TRANSPORTATION BOAT UNITS DATA. B

Range of R_a (or R_b)		Major units		Strength
From	To	HB'_R	HB'	
0	75	—	—	0
76	750	1	—	121
751	1439	—	1	171

(2) $rb/1440 = Q_b + (R_b/1440)$
Q_b = number of HB'.
Use R_b to enter Table A6.

(3) $ip/1440 = Q_c + (R_c/1440)$
Q_c = number of LB'.
Use R_c to enter whatever p~~o~~art of Table A7 is optionally designated in the input.

(4) $ab/480 = Q_d + (R_d/480)$
Q_d = number of FS.
Retain remainder for later computations.

(5) $\frac{op + ip + ap}{1440}$ (rounded) = number of FK

(6) $\frac{rb}{600}$ (rounded) = number of JE

Repeat steps (1) through (6) for each port and beach, developing cumulative requirements for the various units and cells, and a cumulative remainder ΣR_d from step (4). Let $X = 1/10\ \Sigma R_d$.

(7) $X/72 = Q_g + R_g/72$
Q_g = number of AT'.
If $1 \leq R_g \leq 30$, R_g = number of JH. If $31 \leq R_g \leq 40$, allocate one AT'_R. If $41 \leq R_g \leq 65$, allocate one AT'_R and $(R_g - 36)$ JH cells. If $66 \leq R_g \leq 71$, allocate one AT'.

(8) $\frac{IWW}{75} \cdot DD$ (rounded) = number of FC

(9) $\frac{IWW}{600}$ (rounded) = number of FJ

(10) If $IWW \neq 0$, assign one FF.

(11) $\frac{sp}{75}$ (rounded) = number of FA

(12) $HB' + HB'_R + LB' + LB'_R + MB' + MB'_R$ = number of FK (over and above those computed above).

DATA SHEET 5, TERMINAL UNITS

Terminal Commands

(a) Input. TS', TS'_R, SA', SA'_R, AC attached to ports; TS', TS'_R, AC attached to beaches.

(b) Output. TS'', TC'''_A, TC'''_B, TC'''_C, AA, AC, BA, CA, CB, FA, FB, FD, FE, FF, FH, FJ, FL, FM, FN, FO, IA, JD.

(c) Computations.

(1) 0.67 · number of port-attached units + number of beach-attached units = X

(2) $X/24 = Q + (R/24)$
Q = number of TC'''_C.

(3) Use R to enter Table A8.

(4) Use R also to enter Table A9, to obtain augmentation cells identified with the command found in step (3).

(5) Multiply Q by the last row of Table A9, to obtain augmentation cells identified with the commands found in step (2).

TABLE A7

TRANSPORTATION-BOAT-UNITS DATA, C

Range of R_c		Units, option 1				Units, option 2		
From	To	LB'_R	LB'	MB'_R	Strength	MB'_R	MB'	Strength
1	75	—	—	—	0	—	—	0
76	375	—	—	1	145	1	—	145
376	750	1	—	—	179	—	1	206
751	1050	1	—	1	324	1	1	351
1051	1439	—	1	—	301	—	2	412

TABLE A8

TERMINAL-COMMANDS DATA

Range of R		Major units			
From	To	TS''	TC''_A	TC''_B	TC''_C
0	1	—	—	—	—
2	4	1	—	—	—
5	6	—	1	—	—
7	12	—	—	1	—
13	23	—	—	—	1

TABLE A9

TERMINAL-COMMANDS AUGMENTATION DATA, A

Range of R		Augmentation cells																	
From	To	AA	AC	BA	FA	FB	FD	FE	FF	FH	FJ	FL	FM	FN	FO	IA	JD	CA	CB
0	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	6	2	1	—	2	1	1	—	1	1	2	1	1	1	—	1	2	1	—
7	8	2	1	1	1	1	1	—	1	—	4	1	1	1	1	1	3	1	—
9	10	2	1	1	1	1	1	—	1	—	4	1	1	1	1	1	4	1	—
11	12	2	1	1	1	1	1	—	1	—	4	1	1	1	1	1	5	1	—
13	14	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	6	1	1
15	16	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	7	1	1
17	18	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	8	1	1
19	20	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	9	1	1
21	22	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	10	1	1
23	23	3	1	1	2	1	1	1	2	1	6	1	1	1	1	1	11	1	1

The augmentation strengths associated with rows of Table A9 are as shown in Table A10.

DATA SHEET 6, TERMINAL UNITS

Boat-Maintenance Companies

(a) Input.*

(1) 15 HB', 15 HB'_R, 37 LB', 37 LB'_R, 21 MB', 21 MB'_R, FB, FF, FJ, FM, FN, FO, FH.

(2) FC, FD, FE, FH.

(b) Output. BM', FCM', CA, CB, FK, IA, IB, IC, ID, IE.

(c) Computations.

$$\frac{\text{Sum of units in list (1)}}{100}\text{(rounded)} = \text{number of FCM' and number of FK}$$

Method 1: Sum of all input units/146 = Q + (R/146)

Method 2: Sum of all input units/146 = Q (round up)

Q = number of BM'.

Use R to enter Table A11.

DATA SHEET 7, TERMINAL UNITS

Boat Battalions

(a) Input. BM', FCM', HB', HB'_R, LB', LB'_R, MB', MB'_R.

(b) Output. B", B''_R. The computations also affect Data Sheet 8.

(c) Computations.

Sum of input units/22 = Q + (R/22)

Disregard Q (which will always be zero in practice).

If $R = 1$ note this fact for use in Data Sheet 8. If $R > 1$, use R to enter Table A12.

DATA SHEET 8, TERMINAL UNITS

Terminal Service Battalions

(a) Input. SA', SA'_R, TS', TS'_R, AC.

(b) Output. TS", TS''_R

(c) Computations.

Sum of input units + $k/4$ = Q + (R/4)

Q = number of TS".

$k = 1$ if the remainder in Data Sheet 7 was 1, otherwise $k = 0$.

Use R to enter Table A13.

*HB' has 15 craft assigned; MB' has 21 craft assigned; LB' has 37 craft assigned.

TABLE A10

TERMINAL-COMMANDS AUGMENTATION DATA, B

Range		Strength
From	To	
0	4	0
5	6	124
7	8	169
9	10	177
11	12	185
13	14	225
15	16	233
17	18	241
19	20	249
21	22	257
23	23	265

TABLE A11

BOAT-MAINTENANCE-UNITS DATA

Range of R		Major units	55–500				29–500			Strengths
From	To	BM'	IA	IB	IC	ID	IE	CA	CB	
1	7	—	—	—	—	—	—	—	—	0
8	12	—	—	1	1	—	—	1	—	25
13	20	—	—	—	—	1	—	1	—	34
21	30	—	—	1	1	1	—	1	—	55
31	40	—	—	—	—	2	—	1	—	64
41	50	—	—	1	1	2	—	1	1	86
51	60	—	—	—	—	3	—	1	1	95
61	70	—	1	—	—	—	1	1	1	96
71	80	—	1	1	1	—	1	1	1	117
81	90	—	1	—	—	1	1	1	1	126
91	145	1	—	—	—	—	—	—	—	146

TABLE A12

BOAT-BATTALIONS DATA

Range of R		Major units		Strength
From	To	B'_R	B''	
2	5	1	—	58
6	7	—	1	79
8	14	—	2	158
15	21	—	3	237

TABLE A13

TERMINAL-SERVICE-BATTALIONS DATA

Range of R		Major units		Strength
From	To	TS''_R	TS''	
0	1	—	—	0
2	2	1	—	46
3	3	—	1	56

DATA SHEET 9, RAIL UNITS

Railway Operating Battalions

(a) Input. Combined number of switch and road engines, number of railway divisions, and total miles of track.

(b) Output. RO", RE', CA, CB, CC, ED, EE, EG, EJ, EK, EL, EN, EO, EP, EQ.

(c) Computations.

(1) Total engines

Method 1: Total engines/40 = $Q_i + (R_i/40)$

Method 2: Total engines/40 = Q_i (round up)

Q_i = number of RO".
Use R_i to enter Table A14.

(2) Total track length

Method 1: Total track length/150 = $\overline{Q}_i + (\overline{R}_i/150)$

Method 2: Total track length/150 = $\overline{Q}_i$ (round up)

If RO'' < number of divisions, then $\overline{Q}_i$ = number of RE'', otherwise, ignore $\overline{Q}_i$.
Use $\overline{R}_i$ to enter Table A15.

DATA SHEET 10, RAIL UNITS

Railway Shop Battalions

(a) Input. Total number of locomotives.
(b) Output. RS''.
(c) Computations.
Number of locomotives/200 (rounded) = number of RS''

DATA SHEET 11, RAIL UNITS

Railway Headquarters

(a) Input. RO'', RS''.
(b) Output. RG''', RC^x, RS^{xx}.
(c) Computations.
$(RO'' + RS'')/8 = Q_a + (R_a/8)$
Q_a = number of RG'''.
If $R_a \geq 3$, add one RG''' .
RG''' /2 (ignoring remainder) = number of RC^x
RC^x /2 (ignoring remainder) = number of RS^{xx}

Table A14

Railway-Operating-Units Data, A

Range of R_i		Major units	55–500							29–500			Strength
From	To	RO''	ED	EG	EK	EJ	EN	EO	EP	CA	CB	CC	
1	3	—	—	—	—	—	—	1	—	1	—	—	36
4	6	—	1	—	—	—	—	2	—	1	—	—	85
7	9	—	1	—	—	—	—	3	—	1	1	—	117
10	12	—	—	—	—	1	—	4	1	1	1	—	216
13	15	—	—	1	—	1	—	5	1	1	2	—	266
16	18	—	—	1	—	1	—	6	1	1	2	—	298
19	21	—	1	1	—	1	—	7	2	1	3	1	401
22	24	—	1	1	1	1	—	8	2	1	4	1	460
25	27	—	—	—	1	2	1	9	2	1	5	1	518
28	30	—	—	—	1	2	1	10	2	1	6	1	551
31	33	—	1	—	1	2	1	11	2	1	7	1	600
34	36	—	1	—	1	2	1	12	3	1	8	1	686
37	39	1	—	—	—	—	—	—	—	—	—	—	823

Table A15

Railway-Operating-Units Data, B

Range of $\overline{R}_i$		Major units	55–500				29–500	Strength
From	To	RE'	EE	EI	EL	EQ	CB	
1	10	—	—	—	—	—	—	0
11	20	—	1	—	—	—	1	15
21	35	—	2	—	—	1	2	91
36	50	—	3	—	1	1	3	132
51	65	—	4	—	1	2	4	208
66	80	—	5	1	1	2	4	243
81	149	1	—	1	—	—	—	272

DATA SHEET 12, HIGHWAY UNITS

Truck Companies

(a) Input. Total on-road ton-miles, dry cargo (*lh*); total off-road ton-miles, dry cargo (*lo*); and total highway ton-miles, POL (POL).

(b) Output. MT', MT'_R, LT', LT'_R, AA, CA, CB, DA, DE, DG, DI, GD, GE.

(c) Computations.

(1) On-road dry cargo

Method 1: $lh/54000 = Q_a + (R_a/54000)$

Method 2: $lh/54000 = Q_a$ (round up)

Q_a = number of MT'.
Use R_a to enter Table A16.

(2) Off-road dry cargo

Method 1: $lo + POL/27000 = Q_b + (R_b/27000)$

Method 2: $lo + POL/27000 = Q_b$ (round up)

Q_b = number of LT'.
Use R_b to enter Table A17.

DATA SHEET 13, HIGHWAY UNITS

Truck Headquarters

(a) Input. MT', MT'_R, LT', LT'_R; number of field armies (*fa*).

(b) Output. T'', T''', T^x.

(c) Computations.

$(MT' + MT'_R + LT' + LT'_R)/5$ (rounded) = number of T''

T''/5 (rounded) = number of T''' in CommZ

fa/2 (rounded) = number of T''' in CZ

total T'''/5 (rounded) = number of T^x

DATA SHEET 14, HIGHWAY UNITS

Miscellaneous Highway Units

(a) Input. Total number of troops in theater for whom heavy truck computation is applicable (*tt*); total number of rifle companies in infantry division battle groups (*bg*); total highway net miles (*hm*); number of field armies (*fa*); and number of T''. If the campaign involves Arctic operations, these additional inputs are required: number of infantry divisions (*id*) and total number of combat divisions (*cd*).

TABLE A16

TRUCK-UNITS DATA, A

Range of R_a		Major units		55–500			29–500			Strength
From	To	MT'_R	MT'	AA	GE	GD	CA	DA	DE	
1	3000	—	—	—	—	1	—	1	—	17
3001	6000	—	—	—	1	—	—	1	—	17
6001	9000	—	—	—	1	—	—	1	—	17
9001	12000	—	—	1	1	1	1	1	1	40
12001	15000	—	—	1	2	—	1	1	1	40
15001	18000	—	—	1	—	1	1	1	2	57
18001	21000	—	—	1	—	—	1	1	2	57
21001	24000	—	—	1	—	—	1	1	2	57
24001	27000	1	—	—	—	—	—	—	—	80
27001	30000	1	—	—	—	1	—	1	—	97
30001	33000	1	—	—	1	—	—	1	—	97
33001	36000	1	—	—	1	—	—	1	—	97
36001	39000	1	—	1	1	1	1	1	1	120
39001	42000	1	—	1	2	—	1	1	1	120
42001	45000	1	—	1	2	1	1	1	2	137
45001	48000	1	—	1	3	—	1	1	2	137
48001	51000	1	—	1	3	—	1	1	2	137
51001	53999	—	1	—	—	—	—	—	—	181

TABLE A17

TRUCK-UNITS DATA, B

Range of R_b		Major units		55–500		29–500						Strength
From	To	LT'_R	LT'	AA	GD	CA	CB	DA	DE	DG	DI	
1	3000	—	—	—	1	—	—	1	—	—	—	17
3001	6000	—	—	1	2	1	—	1	1	—	—	40
6001	9000	—	—	1	3	1	—	1	2	—	—	57
9001	15000	1	—	—	—	—	—	—	—	—	—	73
15001	18000	—	—	2	6	1	1	1	5	1	—	110
18001	21000	—	—	2	7	1	2	1	6	1	—	128
21001	24000	—	—	3	8	1	2	1	7	2	1	151
24001	26999	—	1	—	—	—	—	—	—	—	—	176

(b) Output. TC'', CC', HT', SL', TC', DA''', C', GA, GF, GG.

(c) Computations.

$4\,(id)$ = number of CC'

cd = number of SL'

$bg/3$ (rounded) = number of TC'*

TC'/2 (rounded) = number of TC''

$tt/100{,}000$ (rounded) = number of HT'

If HT' $\neq 0$, then $2\,fa$ = number of DA'''

$fa + 1$ = number of C'

T'' = number of GA

$hm/40$ (rounded) = number of GG

$2\,(MT' + MT'_R)$ = number of GF

DATA SHEET 15, AVIATION UNITS

Aviation Units

(a) Input. Number of corps (c) and number of field armies (fa).

(b) Output. MH', TA'; LH', AAM', AMS', AM''.

(c) Computations.

$4\,fa$ = number of MH'*

$4\,fa$ = number of TA''

3 TA'' = number of LH'*

c = number of AAM'

fa = number of AMS'

(AMS' + AAM')/4 (rounded) = number of AM''

DATA SHEET 16, OTHER UNITS

Intelligence and Movement-Control Teams

(a) Input. Number of corps (c), number of field armies (fa), and number of CommZ sections (s).

(b) Output. MC''', MC'''_R, HA, HB.

(c) Computations.

$fa + c + 1$ = number of HA

$fa + 2$ = number of HB

fa = number of MC'''

s = number of MC'''_R

To compute strengths, MC''' and MC'''_R typically have the following compositions:

$$MC''' = 1\ AE + 8\ LA + 13\ LB + 14\ LC + 2\ LE$$

$$MC'''_R \equiv 1\ AE + 1\ LA + 3\ LB + 3\ LC + 6\ LD + 3\ LE - 1$$

*Nondivisional combat units.

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